Proceedings of the 1983 SOUTHERN FOREST BIOMASS WORKSHOP

Charleston, South Carolina
June 15-17, 1983

Edited by: R. F. Daniels
P. H. Dunham

Proceedings of the 1983 SOUTHERN FOREST BIOMASS WORKSHOP

Fifth Annual Meeting of the Southern Forest Biomass Working Group

Charleston, South Carolina
June 15-17, 1983

Edited by
R. F. Daniels and P. H. Dunham
August 1984

Sponsored by
The Biometrics Group of the Forest Science Laboratory
Westvaco Corporation
Summerville, South Carolina

Published by the USDA Forest Service,
Southeastern Forest Experiment Station,
Asheville, North Carolina

FOREWORD

The Fifth Annual Meeting of the Southern Forest Biomass Working Group was held in Charleston, South Carolina on June 15-17, 1983. The meeting was hosted by the Biometrics Group of Westvaco Corporation's Forest Science Laboratory.

The theme of this year's meeting deviated somewhat from past meetings. Traditionally, the Working Group meetings have served as a forum for the informal exchange of research ideas and results among researchers working in the field of forest biomass. In the past few years, attendance has grown to include non-researchers interested in incorporating these results into their areas of responsibility. It was the intent of this year's meeting to provide a balanced program with topics of interest for those involved in the application of forest biomass-related techniques and yet still retain the traditional flow of information among researchers. It was hoped that both the researcher and the practitioner would benefit from the association. This publication documents the Proceedings of the meeting and provides a permanent record for all people requiring the most recent information on biomass as related to southern forestry.

The papers are arranged under each session in the order in which they were presented. For the informal session, Session 5, abstracts are included for those authors wishing to have them published in the Proceedings. A brief summary of the business meeting and the results of a questionnaire concerning the status and future direction of the Working Group conclude the Proceedings.

The papers presented in the formal sessions were received in camera-ready form for publication. As such, the authors have sole responsibility for the contents of their papers.

Special recognition must be given to the session moderators for the outstanding job they did in organizing and maintaining their sessions. We would also like to gratefully acknowledge the following people: Mr. Edwin G. Owens, Director of Forest Research at Westvaco for his welcoming address; Dr. V. Clark Baldwin, Southern Forest Experiment Station and last year's Workshop Chairman, for the invaluable aid in the overall organization of this year's meeting; Dr. Charles A. Gresham, Clemson University for further organizational assistance; and lastly, several Westvaco personnel whose behind-the-scenes activities contributed greatly to the success of the meeting. Specifically, we wish to acknowledge the efforts of Mrs. Marlene Lloyd, Mrs. Carol Knight, Mr. Neal Menkus and Mr. Casey Canonge.

Finally, we gratefully recognize the help Mr. Joseph R. Saucier has provided in coordinating the publication of this Proceedings through the U.S. Forest Service's Southeastern Forest Experiment Station.

R. F. Daniels
P. H. Dunham
Workshop Co-chairmen

408992

TABLE OF CONTENTS

SESSION 1

IMPACT OF THE TOTAL BIOMASS CONCEPT ON TRADITIONAL FORESTRY PRACTICES

Moderator: William R. Harms

THE TOTAL BIOMASS CONCEPT:

ITS IMPACT ON TRADITIONAL SILVICULTURE[1]

R. C. Kellison[2]

Abstract.--Price decreases of petroleum products, advanced technology for burning low-grade fossil fuels, and relaxation of environmental standards are responsible for decreased emphasis on the biomass concept. Energy plantations which were advocated a few years ago for fuel and chemicals have temporarily lost their purpose, although good silvicultural information has been obtained for translation to other types of plantations.

The greatest use of forest biomass in the Eastern Hardwood Forest, other than for traditional forest products, will be for home heating and cooking and for energy generation in manufacturing facilities of the forest products industry. The forest products industry is more than 50% energy self-sufficient, and the goal is to become totally self-sufficient. About 60% of that fuel will be mill residues and the remainder forest residue. Forest residue at today's prices is too costly to compete with fossil fuels but that situation will eventually be reversed. Removal of the forest residue in harvested stands, and especially in low-grade stands having no higher end use, will allow for stand replacement with trees of higher value. Silvicultural practices will generally be favorably affected by biomass removal; site productivity may be adversely affected by repeated biomass harvests.

INTRODUCTION

The oil embargo of 1973-74 caused almost all the developed nations of the world to search for alternative sources of fuel. The United States became particularly involved because of previous complacency. With the exception of nuclear energy, we had opted to ignore pending fuel shortages despite the warnings of such brilliant minds as Paul Erlich, the population-control advocate, and Walt E. Rostow, the policy economist. The United States reacted to the emergency with panic. The Energy Research and Development Agency (ERDA), which later evolved into the Department of Energy (DOE), was formed to establish policy and programs. Similar programs were formed by other public and private organizations. The result was a series of programs that were competitive with one another, even to the point of being counterproductive. Only in recent years has DOE risen to the fore to administer public-funded energy research.

Among the many sources of energy, woody crops have caught the attention of the forest industry, light industry (textiles, brick, furniture), public institutions (schools, hospitals, power plants), and homeowners. Potential use was calculated to be so great, increasing from about two to eight percent of the total domestic energy budget (Youngquist, 1981), that concern was expressed about a continuing supply and about maintaining site productivity where the total above-ground biomass was to be removed at frequent intervals. This concern resulted in plantation programs of short-rotation woody crops. The other alternative was to capitalize on available natural stands. This paper addressed the attributes and limitations of each of the strategies, with special emphasis placed on the impact of the biomass concept on traditional silviculture.

[1] Presented at the Fifth Annual Southern Forest Biomass Workshop, Charleston, South Carolina, June 15-17, 1983

[2] Professor and Director Hardwood Research Program, North Carolina State University, Raleigh, North Carolina.

SHORT-ROTATION WOODY CROPS (SRWC)

Among the many reasons for placing emphasis on plantation culture for biomass production are stocking control (intraspecific), competition control (interspecific), row integrity which allows for more efficient use of site preparation and harvesting equipment, genetic improvement, and location of the wood resource withing a reasonable haul distance of the high-cost energy generating plant. A first concept was to establish the energy plantations on land of limited value for other crops. The first two test plantings we established were relegated to the marginal sites, one to a floodplain of the Roanoke River in Bertie County, N.C. and one to a Whitestore soil series of tertiary origin in Granville County, N.C. The former site, which is highly fertile but often inaccessible because of standing water, was inundated until late May of the year of planting, causing poor survival from prolonged seedling storage and late planting. Tree survival and growth were similarly affected the second growing season because the high waters prevented disking for competition control until well past the optimum time. Optimum growth of the surviving trees was delayed until the third and fourth growing seasons (Table 1).

The Granville County site was abandoned for farming about 50 years ago because the soil physical and chemical properties had been seriously depleted. The succeeding marginal crop of loblolly pine, red cedar, sweetgum and oak was evidence of the poor site. The SRWC planting, consisting of European black alder, black locust, sweetgum and loblolly pine has been disappointing despite efforts to augment tree growth by controlling competition and applying nutrients (Table 2). The species blocks of black locust were abandoned because of poor survival. Experience shows that the energy plantations will have be grown on the best sites instead of the worst if target yields of six to eight dry tons/acre/year are to be obtained. This conclusion augments results obtained by organizations growing hardwoods in plantations for pulp fiber and structural lumber (Malac and Hereen, 1979).

Complete-tree utilization which encompasses the use of all below- and aboveground parts of a tree has been advocated for fiber and energy production (Koch, 1974). About 25% greater yield is obtained than is available only from the aboveground portion. This concept appears to have limited value for energy plantations because a basic premise for economic justification of woody crops for energy is that two or more coppice crops will be obtained, in addition to harvest of the seedling crop. If coppicing is a prerequisite, energy plantations will be comprised almost solely of hardwoods. While we are not convinced that confiers should be excluded from energy plantations, we are convinced that consideration will have to be given to the season of hardwood harvest. Sycamore, harvested at five dates during the thirteenth growing season, sprouted profusely the first year when cut before June 30; the maximum number of sprouts from the August and October harvests did not occur until the following year. The green biomass (tons/acre) from the March harvest is significantly greater after three years than any of the other treatments (Figure 1). Part of this difference is due to a longer growing period, but part is also due to season of harvest. The possibility exists that the adverse affects of late-season harvests could be offset by the application of silvicultural practices. If the limitations cannot be corrected, a stated advantage of woody crops over annual biomass crops would be lost because they could not be "stored on the stump" for harvest at any time of year as has been advocated.

Too little information exists to draw definitive conclusions about the nutrient drain resulting from frequent removal of short-rotation woody crops. Based on tissue analysis in the Granville County planting, the removal of N, P, K, Ca and Mg after the fourth growing season from European black alder and sweetgum is about twice as great at the 2.5 x 5-foot spacing as at the 5 x 5-foot spacing. Nutrient removal in loblolly pine biomass is comparable to that from European black alder but different from that of sweetgum (Table 3).

The tentative conclusion is that nutrient depletion will occur and that the physical structure of the soil will be adversely affected (Mitchell, 1981) unless efforts are made to amend the limitations.

NATURAL STANDS

There are about 190 million acres of commercial forest land in the South, of which only about 25 million acres are in pine plantations and about 100,000 acres are in planted hardwood stands. A significant proportion of that land is occupied by low-grade hardwood stands for which there is limited market. Additionally, only about two-thirds of the biomass of about 50 dry tons/acre are removed during harvesting operations on industrial lands (Hughes and McCollum, 1982). The wood waste on nonindustrial private land is almost surely greater than that on industrial land. The economic feasibility for using this material over that obtained from energy-intensive plantations is accepted by those using wood for fuel.

The forest industry has increased energy self-sufficiency from about 25 to over 50% since the oil embargo of 1973-74. Much of that saving which has come at the expense of #6 fuel oil has accrued from the burning of black liquor, but a significant proportion has been obtained from mill residue. However, mill residue often has a higher end value than for fuel, such as green chips and sawdust for pulp, dry chips for particleboard, and bark nuggets for landscaping. Numerous feasibiliy

Table 1.--Mean survival and height of seven species after two and four growing seasons on a red river bottom in Bertie County, N. C.[1]

Species	2-Year Measurement		4-Year Measurement	
	Survival (%)	Height (ft.)	Survival (%)	Height (ft.)
European Black Alder	58	3.6	60	15.3
Eastern Cottonwood	59	2.0	56	13.7
Green Ash	99	3.0	99	9.8
Water-Willow Oak	69[2]	1.4	92	4.6
Sweetgum	69[2]	1.6	76	7.5
Sycamore	87	3.6	93	16.7
Loblolly Pine	52	1.3	52	7.1

[1] Spacings of 2.5 x 5 feet, 5 x 5 feet, and 8.3 x 5 feet were used, but only the 5 x 5-foot data are shown.

[2] Survival differences are due to top dieback and sprouting.

Table 2.--Mean survival and height of three species after two and four growing seasons on a Piedmont upland soil in Granville County, N.C.[1]

Species[2]	2-Year Measurement		4-Year Measurement	
	Survival (%)	Height (ft.)	Survival (%)	Height (ft.)
European Black Alder	89	1.9	68	9.1
Sweetgum	88	4.0	87	5.3
Loblolly Pine	87	1.9	91	6.5

[1] Spacings of 2.5 x 5. feet, 5 x 5 feet and 8.3 x 5 feet were used, but only the 5.5-foot data are shown.

[2] Black locust performed so poorly that the species blocks were abandoned.

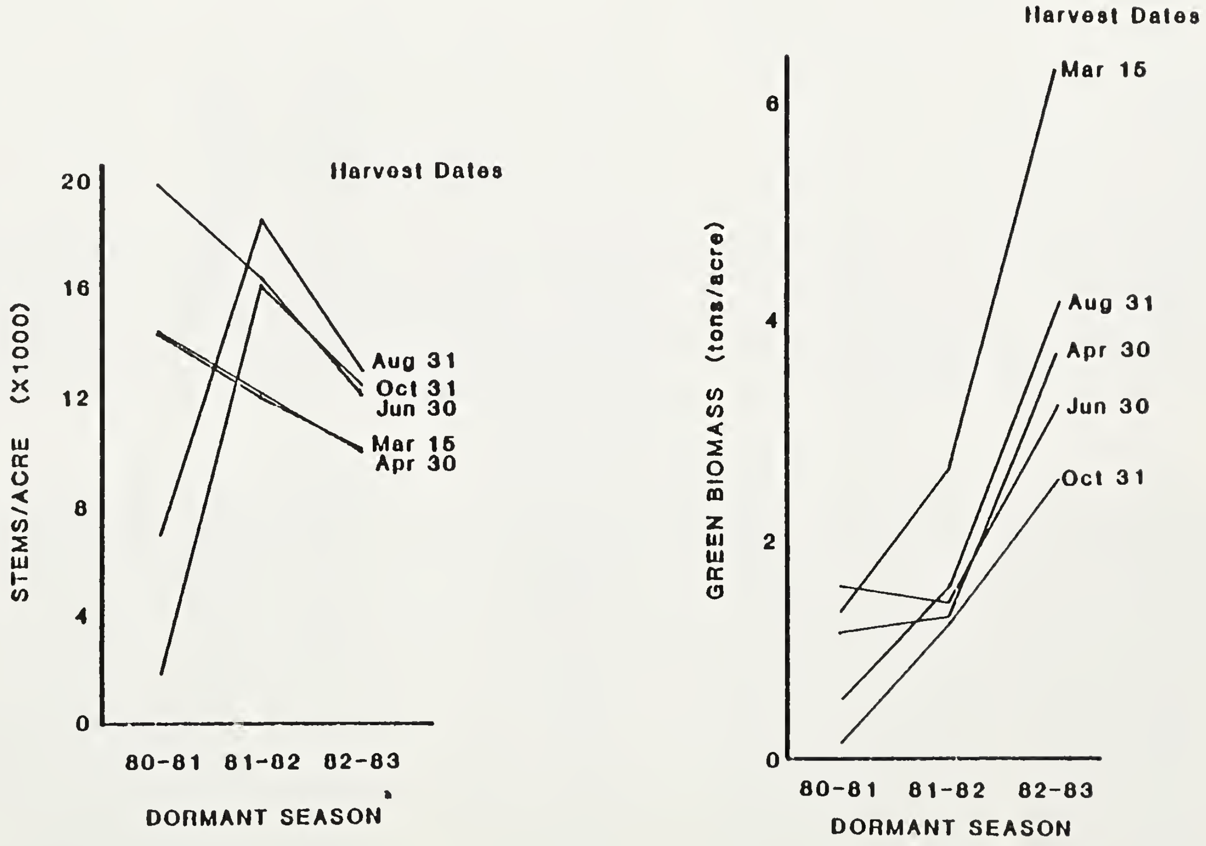

Figure 1. Stand development (stems/acre) and productivity (green biomass) of coppice regeneration during the third dormant season following five harvests in 1980 of a 12-year-old sycamore plantation

studies and pilot-plant projects have been conducted to determine the worth of forest residue for fuel. The economics were attractive until about 1979, when oil prices were at record-high levels. Since that time, however, interest in wood residue for fuel has waned, as technology has developed to allow the burning of high-sulfur coal and as oil prices have decreased. The few organizations that continue to collect forest residue conclude that the wood must be free stumpage and that it be located within a 25-mile radium of the mill.

A value that accrues to biomass harvesting of natural stands is a concomitant reduction in site preparation costs. Unfortunately, our tax laws are structured so that all of the cost has to be charged against harvesting; none can be charged to site preparation as long as the resource is being processed. This ruling has been a detriment to land cleaning for regeneration purposes.

Research has shown that about 20% more biomass is obtained from whole-tree harvesting of green ash on an individual-tree basis, as opposed to conventional harvesting (Messina, 1980) (Table 4); as much as 100% biomass overrun can be realized from high-graded stands. The extra 20%, which contains top wood, top bark, branches and foliage, contains about as much nitrogen as the 80% contained in the conventionally harvested timber. Similar results occur for phosphorus and magnesium. Calcium and potassium are concentrated more heavily in the bole wood and bole bark than are the other three elements.

Insufficient time has elapsed to determine whether whole-tree harvesting will deplete the site of nutrients. Evidence is accumulating to show that net primary production for P, K, Mg and Ca during the first year after harvest in a clearcut hardwood stand was 29% to 44% of that of the control, where the control was undisturbed. Based on these rapid inputs, on the fixation of nitrogen by colonizing legumes, and on rotations greater than 30 years, significant nutrient depletions do not appear to be a reality (Boring, et al., 1981).

Trials have been conducted to determine whether biomass harvesting should be completed before, during or after harvesting the main stand. Preharvesting can be done most easily because of the absence of logging debris and stumps, and it leaves the main stand in good condition for immediate or delayed harvesting. Postharvesting has the advantage over preharvesting in that more biomass is available from the tops of trees forming the main stand. However, both of these harvesting systems are less desired than the combination system, where the stand is merchandised for biomass, pulpwood and sawtimber at a common time. The key element to the combination system is economic efficiency; all wood is skidded to the logging deck, where sorting occurs.

IMPLICATIONS

I do not think short-rotation woody crops will be grown for combustion fuel in the southern United States any time in the next 30 to 50 years. Plantation wood, if it is to be grown for fuel, will be used for chemical manufacture rather than for direct combustion. Short-rotation woody crops can be successfully grown but only on the best sites and with the best silviculture. Nutrient depletion and alteration of soil physical properties will likely result from intensive short-rotation plantation management. Steps will have to be implemented to maintain site productivity.

The greatest opportunity for energy supplements from forest biomass is in natural stands, primarily in the low-grade deciduous hardwood stands. At present the cost of collecting forest residue is prohibitive beyond a radius of 25 miles from the generating plant and when the timber has a positive stumpage value.

Biomass harvesting has a twofold value--supply of a wood resource for energy production and product manufacture, and removal of the forest residue to alleviate site preparation costs and efforts for the ensuing crop. Unfortunately, tax laws do not encourage improved harvesting to lessen the cost of site preparation. The most efficient harvesting system is to merchandise all timber for biomass, pulpwood and sawtimber at the time of harvest of the main stand.

Nutrient depletion is not anticipated from biomass harvesting of natural stands because most of the effort will be to replace an inferior stand with an improved stand. Coppice rotations in natural stands will usually exceed 30 years, which is apparently sufficient time for site recovery.

Both natural stands and woody crop plantations will play an increasingly active role as energy supplements. However, major activity will not ensue until after the year 2000, when petroleum-based products increase in value from an ever-decreasing supply.

LITERATURE CITED

Boring, L. R., C. D. Monk and W. T. Swank. 1981. Early regeneration of a clearcut Southern Appalachian forest. Ecol. 62(5):1244-1253.

Hughes, C. M. and M. P. McCollum. 1982. Needs and future directions for biomass research and application from an industrial viewpoint. Proc., Fourth South. For. Biomass Workshop, So. For. Expt. Sta. New Orleans, La. pp. 3-15.

Koch, P. 1974. Full-tree utilization of southern pines and hardwoods growing on southern pine

Table 3.--Nutrient content of three species at three spacings after four growing seasons on a Piedmont upland soil in Granville County, N.C.

Species	Spacing (ft.)	N	P	K	Ca	Mg
		---------------	-------	lb./ac.	-------	---------------
European Black Alder	2.5 x 5	49.1	3.6	24.6	19.6	6.2
	5 x 5	20.9	1.5	10.5	8.3	2.7
	8.3 x 5	21.8	1.6	10.9	8.7	2.8
Sweetgum	2.5 x 5	10.1	1.0	5.3	14.0	4.5
	5 x 5	4.8	0.5	2.5	6.6	2.2
	8.3 x 5	3.0	0.4	1.9	5.1	1.6
Loblolly Pine	2.5 x 5	19.6	3.1	12.1	4.7	2.4
	5 x 5	37.5	5.0	17.6	6.8	3.3
	8.3 x 5	17.4	2.3	8.0	3.1	1.5

Table 4.--Dry weight and nutrient content of green ash expressed as percentage of aboveground totals[1/]

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	72.6	39.0	42.9	54.9	23.5	37.8
Bole Bark	7.1	14.0	6.3	10.4	43.7	20.1
Bole Subtotal	79.9	53.0	49.2	65.3	67.2	57.9
Top Wood	1.5	2.5	5.2	2.8	1.1	2.3
Top Bark	0.3	1.0	0.5	0.9	1.9	1.3
Branches	17.0	24.1	34.4	21.3	23.5	24.7
Leaves	1.5	19.4	10.7	9.7	6.3	13.8
Top Subtotal	20.3	47.0	50.8	34.7	32.8	42.1

[1/]From Messina, M. G. 1980. Biomass and nutrients relationships in Coastal Plain hardwoods.

sites: Optimizing the South's forest resources. Proc., Second Regional Tech. Conf., SAF. pp. 106-120.

Malac, B. V. and R. D. Heeren. 1979. Hardwood plantation management. S. Jour. Appl. For. 3(1):3-6.

Messina, M. G. 1980. Biomass and nutrient relationships in Coastal Plain hardwoods. Proc., First Biennial Southern Silvicultural Res. Conf., Atlanta, Ga. pp. 242-247.

Mitchell, M. 1979. Loblolly pine (Pinus taeda) seedling establishment as influenced by soil compaction. M. S. Thesis, School of Forest Resources, N. C. State Univ., Raleigh. 38 pp.

Youngquist, J. A. 1981. Develop family of flakeboard products. Proc., Fifteenth Inter. Symp. on Particleboard. Wash. State Univ., Pullman, Wash. 13 pp.

THE COMPLETE TREE CONCEPT: ITS IMPACT ON FOREST MENSURATION[1]

Virgil C. Baldwin, Jr.[2]

Abstract.--The introduction of the concept of complete tree utilization, with weight rather than volume as the primary measure of forest tree and stand growth and yield, has brought many changes. There is a need for adaptation in sampling techniques and equipment, in computation methods and data collection and analysis, and in education requirements for both researchers and practitioners.

INTRODUCTION

The concept of complete- or whole-tree utilization has affected forest mensurational thought and technique, primarily by compelling the use of weight measure to supplement or largely replace volume measure in describing forest trees and associated woody plants. Additional data and expanded analyses are needed if yield predictions are to be made for all forest resources, rather than timber alone, and output information from forest yield prediction systems must be more versatile. All of these changes call upon practitioners and scientists to revise their thinking and even to supplement their training.

This paper reviews the history of these innovations and discusses their effect on current and future mensurational thought and practice.

PAST AND FUTURE OF THE CONCEPT

Many people have contributed to the development of the complete-tree utilization concept. In this country, the paper by Sproull, Parker and Belvin (1957) was significant for forest products utilization. They reported that it was possible to make good quality pulp from all woody components (except bark) of southern pine trees. Then, at the 1964 annual meeting of the Society of American Foresters, Harold Young formally introduced the "Complete Tree Concept" (1964). Basically he proposed that the entire tree become the primary forest product rather than just the "merchantable" bole portion. Ever since then interest in the utilization of trees in all their component parts has been spreading.

In 1975, R.J. Auchter of the U.S. Department of Agriculture Forest Products Laboratory, speaking at the TAPPI Alkaline Pulping Conference (Auchter 1975), discussed opportunities and problems associated with whole-tree untilization. Among the problems he cited was the need for "new volume tables based on what is now the usable and merchantable wood resource", and for "...some idea of the make-up of the volume-percentage of bole, limbs and tops". Work on solving the mensurational problems had started in earnest at least a decade before then and the primary mensurational problem was one of estimating tree yield in terms of weight rather than volume.

The traditional use of volume as a measure of tree yield was quite natural. Until the 1960's, the tree bole was generally the only portion of the tree that was considered merchantable. In softwoods particularly, the bole portions of a tree could be approximated as one or another solid of revolution depending upon the section of the bole that was being measured. By using diameter and length measurements the volumes of these solids could be used to estimate the volume of the bole section. These measurements, essential for sawlog volume estimates, were of lesser importance for pulpwood. Here, the traditional measure of a stack of wood of specific dimensions (the cord) was favored mainly because it was quick and inexpensive. The cord was simple to visualize, easy to measure, and accurate enough to meet the needs of the industry until large increases in the value of wood occurred in the 1960's.

History has shown that the forest products industry, the processors, and the final users have determined the forestry unit of measure. For example, Husch and others (1982) pointed out that the board-foot measure is "an attempt to estimate, before processing, the amount of lumber in logs and trees. This is rather unique Few raw materials are measured in terms of the finished product. It is somewhat like trying to measure the yield of field corn in terms of boxes of corn flakes".

1/ Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

2/ Author is Principal Mensurationist, USDA Forest Service, Southern Forest Experiment Station, Pineville, LA 71360.

Why then use weight as a measure of forest product yield? Husch and others (1982), also identified four points on which a decision between weight and volume measures would be based:

Physical characteristics of the substance

Logicalness of weight as an expression of quantity

Feasibility of weighing

Relative cost of weighing.

The trend toward the use of weight measure is mainly based on the first two or three points. The boles can be adequately described in terms of volumes of various solids of revolution, but limbs, branches, twigs, foliage and roots cannot. Neither can a volume measure accurately describe the yield of an entire tree or its nonbole components. These are irregularly shaped solids. Furthermore, since many, if not most, derived forest products such as paper pulp are measured in weight, only by using weight can one effectively integrate the yield of all tree components.

Of course some physical problems are associated with the use of weight measure in the forest products industry. Green weight is highly variable--only the dry weight of plant material is constant. Green weight includes the weight of the water in the product, which can be considerable. Water content varies in standing trees diurnally, seasonally, geographically, and altitudinally, and tree components start losing moisture in varying amounts and rates immediately after being cut. Therefore, since it is not practical to buy, sell, or inventory forest products directly on a dry-weight basis, pricing problems arise when, for example, logs or chips are not delivered and weighed soon after cutting. Inventory and accounting problems may also occur if wood is left in the mill's yard any length of time.

Furthermore, there is a practical problem associated with using weight, especially for sawtimber. It's the same problem that has, for instance, prevented the widespread use of cubic-foot rather than board-foot volume measure; namely, a strong reluctance to change the widely accepted, traditional practices of the past.

Because of these issues, it does not appear that weight measure will entirely replace the various volume measures of forest products, but it will probably become the overall integrating measure of forest yield. The weight prediction equations for tree components in use today offer much more and more useful yield information than bole volume equations alone. With weight-to-volume conversion factors, the bole volume information is available also. So the user cannot only merchandise the standing tree crop but also make better informed management decisions as to other uses.

Weight is the only practical measure by which the productivity of an entire area can be assessed as a whole entity, or in terms of all its components (see in particular Young 1973, 1978a). Biomass measurement also enables us to estimate the total value of an area with respect to all potential uses. We must be able to quantify on a common basis in order to determine value simply and accurately.

Finally, the total tree utilization concept, with its accompanying requirement of weight measurement, provides a common foundation for greater unification of, and cooperation between, all natural resource disciplines.

IMPACTS

Given that the complete-tree utilization concept is here to stay, and its acceptance and practice will continue to be more enlarged and diversified, it is instructive to be aware of its specific effects on the practice of forestry now and in the future. However, only the effects on mensurational thought and practice are considered in this paper. In particular, in this section, influences on different aspects of yield prediction equation development and application will be discussed. Consideration is also given to the importance of understanding the new concepts and techniques required for full implementation of the complete tree utilization concept, and the need for strong primary and continuing education of researchers and practitioners.

Mensuration in Practice

A. Prediction Equation Development

Field and laboratory procedures.--Tree biomass equations and stand biomass yield tables are obtained by destructive sampling and subsampling techniques very similar to tree volume and stand volume yield sampling procedures. The main difference is an increase in the number of measurements (linear and weight) that must be taken on each tree both in the field and in the laboratory. Estimating the volume of a softwood tree 12 inches d.b.h. and 70 feet high, including felling, bucking and d.o.b.-d.i.b. taper measurement time, would probably take only one man-hour. But in a complete aboveground component biomass study, field measurements and weighing for the same tree might take as long as 8 man-hours and an additional 3 man-hours for the laboratory work. Smaller trees go faster, and larger ones take longer, but on the average it

probably takes up to 10 times longer to collect tree-biomass data than to collect tree-volume data.

The field and laboratory work needed carries with it requirements for instrumentation, materials, and laboratory space. Whatever tree components one wants to be able to estimate must first be weighed green in the field. Various configurations and types of scales are used to accomplish this. The entire tree, or the entire bole, or the bole to some top diameter limit may be weighed. The components must usually be cut up into easily handled pieces for weighing on scales of about 300 pounds capacity.

If, as is now common practice, a subsample of the various components is taken for laboratory analysis and dry-weight estimation, the samples must be sealed in plastic bags heavy enough to prevent moisture loss. They are then transported to a laboratory for immediate green weighing or are placed in coolers for storage until the weighing can be accomplished. After green volumes are determined for specific gravity calculations, samples are dried in ovens (some must be large) until moisture loss ceases. Then they are again weighed to obtain dry-weight estimates. All of this requires relatively expensive field and laboratory equipment which is not needed for volume estimation.

Data analysis and modeling.--A significant impact of whole tree utilization on mensurational procedures is in data collection and analysis procedures used to develop the prediction equations. Until recently there were no specific guidelines and scientists were pretty much on their own. The result has been basically a large number of good equations based on data from local studies and data sets which often cannot be combined to produce more regionally applicable equations.

Actions taken to solve this problem include suggested universal procedures that would insure biomass data compatibility and thorough sampling (Alemdag 1980, Clark 1979). Also, at the first meeting of The Southern Forest Biomass Working Group, those present approved a biomass studies guideline that specified minimum standards for collection of biomass data and reporting of analysis results[3].

[3] Standardization statement is printed in Memorandum 1 dated 16 July 1979 from the Steering Committee to all members of the Southern Forest Biomass Working Group.

A computer is practically essential for the preparation of biomass prediction equations, because of the large amount of data per tree which must be edited, sorted into appropriate files for analysis, analyzed, and modeled. Linear and nonlinear equation-fitting programs must be available or must be written to suit. Graphics capability is extremely helpful during the prediction-model selection phase. A researcher would be very hard-pressed to develop equations or summarize biomass data without the aid of computers. Their role in development of the complete-tree utilization concept in forestry is very important.

Most biomass models proposed thus far have predicted weight of whole trees or various individual components using the predictor variables diameter at breast height squared (D^2) or D^2 times total tree height (D^2H). These equations may be linear or nonlinear in form. Generally these models are the same as those that might be used to predict bole volume. In most cases they give adequate results. Phillips and Saucier (1979) tested a number of equations based on the D^2H model and found them to be quite accurate. Therefore it is common to see the same model form used to predict all tree components--only the coefficients change.

However, the crown components (branches, twigs, foliage) are not well predicted using D^2 or D^2H. To obtain more accurate and precise estimates it is necessary to use another predictor variable. For example, any one of a number of upperstem diameter points, such as diameter at the base of the live crown (Clark 1982), has been shown to improve crown weight predictions when used alone or with D^2, or with D^2H.

A significant capability of biomass modeling is component weight prediction additivity. That is, if the mensurationist was careful in data collection, and judicious in model selection and analysis technique, weight predictions from each of the tree component equations will add up to be the same weight as that predicted by the total tree weight equation (Kozak 1970, Jacobs and Cunia 1980). Although one would logically expect this property, it is not automatically achieved. It is important because when it is accomplished, a user can more accurately predict, before harvest, numerous alternative product combinations from a forest tree or stand.

When a nonlinear model is made "linear" with respect to its parameters by a logarithmic transformation, and the "linear" parameters are correctly estimated by least-squares analysis of the data, the resulting transformed equation has all the commonly known favorable properties of linear regressions (e.g., the estimated para-

meters are unbiased and have minimum variance). However, the required antilogarithm predictions obtained from these transformed equations are usually small underestimates of the quantities desired. It is interesting to note here that the logarithmic transformation was commonly used in many biology and forestry modeling applications and the bias was apparently unknown or ignored by most people until biomass researchers brought the problem to light (Baskerville 1972). Since then this relatively minor problem has received a lot of attention in the forestry literature (e.g., Flewelling and Pienaar 1981, Yandle and Wiant 1982).

In most recent studies, volume as well as weight, equations are fitted to the data for the woody components of the tree or alternatively, weight-to-volume conversion formulae are given. The conversion formulae will probably continue to be developed so users may have the option to look at predicted volumes whenever they desire. And these various options will soon be commonly available outputs for users of growth and yield prediction systems. All of these modeling problems, and opportunities, have surfaced as a result of the interest in complete-tree utilization.

B. Applications

The impact of the complete tree utilization concept on forest inventory direction and output has been considerable, particularly within Federal resource agencies. In the past the regional and statewide inventories conducted by the Forest Inventory and Analysis (FIA) projects of the U.S. Forest Service typically emphasized estimation of the volume of wood in trees 5.0 inches and larger d.b.h. from a 1-foot stump height to a 4.0-inch (d.o.b.) top diameter growing on commercial forest land. Fortunately that practice has changed drastically.

Since about 1975, FIA inventories have been both more intensive and more extensive, with significant emphasis not only on standing whole-tree and tree-component biomass but also on sub-merchantable (< 5.0 inches d.b.h.) trees, shrubs, vines, grasses and forbs. The surveys now are truly multiresource inventories and it is the biomass concept (with its use of weight) that enables all of these resources to be measured, and combined or compared in terms of yield or production. To accomplish these and other changes, sampling procedures have been altered and new cruising procedures developed affecting both input and output of data (see for example, Clark and Field 1981, Phillips and Saucier 1981, Young 1973, 1978b). Through the use of volume-to-weight conversion formulae, biomass predictions are now available for regions, states and even the entire United States (see for example, Knight and McClure 1981, Cost and McClure 1982, U.S. Dep. Agric. For. Serv. 1981).

Mensuration Education

The impacts of the total biomass concept that have been discussed here also point to the great need for continuing education of both mensurationists and practitioners. To keep up with the increased potential for biomass prediction requires both intensive and extensive training in prediction techniques and utilization options. For the mensurationist, technical advances in modeling techniques and computing are coming about so rapidly that it is difficult to stay in the mainstream of knowledge. Mathematical, statistical, and computation skills that were satisfactory ten years ago are often inadequate today. Though generally still valid and applicable, they are sometimes of limited usefulness. For example, mainly because larger and faster computers are available, nonlinear models are increasingly used in forestry prediction applications. Fitting these models to data is much easier now than it was in the past. But with this power comes potential problems also. As a rule, nonlinear regression techniques were not a part of the graduate programs of today's practicing mensurationists. The knowledge required to correctly use such techniques must be gained if the results of current research are to be effective.

In this connection, it is interesting to note how whole-tree utilization, with its emphasis on weight measure, has influenced the writers of mensuration textbooks over the last three decades. In three popular textbooks in use during the 1950's (Bruce and Schumacher 1950, Meyer 1953, Spurr 1952) there is no reference to weight measurement or of nonbole component utilization, nor is there anything in the Forestry Handbook (Forbes 1955) pertaining directly to tree weight yields. T.E. Avery's Forest Measurements (1967) and the mensuration textbook by Husch (1963) both have sections on measuring wood by weight, with emphasis on weight-scaling of pulpwood bolts and sawlogs. In addition, Husch included a thoughtful discussion of weight versus volume as a measure of forest products, and made a prediction that weight would be increasingly employed.

In the second editions of the last two mentioned books (Avery 1975, Husch and others 1972) the amount of emphasis given to weight as a measure of forest products had increased noticeably in both cases. And in the most recent editions of these books (Avery and Burkhart 1983, Husch and others 1982) all the authors strongly address the importance of weight estimation in mensurational training and provide some instruction in constructing and understanding tree weight tables for prediction of the weight of standing trees.

Even though new foresters are being taught more about biomass estimation, it is obviously not enough, however. To be up to date with

research progress, we must continually study the material reported and disseminated in the literature and at meetings such as ours. It is imperative that researchers and practitioners stay continually involved.

SUMMARY

The purposes of this paper were to show the effect that the complete-tree utilization concept has had, and will have, on forest mensurational thought and practice, and to point out changes which forestry researchers and practitioners must make in order to stay in the mainstream of this movement.

The history of the whole-tree utilization concept was reviewed and the necessity of using weight as the primary measure of forest products discussed. Although volume measure, in addition to weight measure, will still be used for some products, weight or biomass will probably become the measurement standard because of its greater overall versatility and comprehensiveness.

These changes have significantly increased the amount of field work, and field and laboratory equipment, needed to prepare biomass prediction equations. Data analysis and modeling has become somewhat more complex requiring use of computers and new prediction techniques. Significant changes in modeling emphasis have occurred. Resource inventory procedures have also changed to allow not only weight estimation of various tree components, but of all the stand vegetation. And overshadowing all of these changes is the need for a strong and immediate expansion of education in biomass prediction research procedures and user applications.

LITERATURE CITED

Alemdag, I.S.
1980. Manual of data collection and processing for the development of forest biomass relationships. Information Report PI-X-4. Petawawa, Ontario, Canada: Environment Canada, Canadian Forestry Service, Petawawa National Forestry Institute; 38 pp.

Auchter, R. J.
1975. Whole-tree utilization: fact or fantasy. TAPPI 58(11):4-5.

Avery, T. E.
1967. Forest measurements. New York: McGraw-Hill; 189 pp.

Avery, T. E.
1975. Natural resource measurement. 2d Ed. New York: McGraw-Hill; 339 pp.

Avery, T. E., and H. E. Burkhart.
1983. Forest measurement. 3d Ed. New York: McGraw-Hill; 330 pp.

Baskerville, G. L.
1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49-53.

Bruce, D., and B. S. Schumacher.
1950. Forest mensuration. 3d Ed. New York: McGraw-Hill; 483 pp.

Clark, A., III.
1979. Suggested procedures for measuring tree biomass and reporting tree prediction equations. In: Frayer, W. E. ed. Forest resource inventories: Proceedings of a workshop; 1979 July 23-26; Fort Collins, CO: Colorado State University, Department of Forest and Wood Sciences; Vol. 2, pp. 615-628.

Clark, A. III.
1982. Predicting biomass production in the south. In: Hotvedt, J.E. and B.D. Jackson, eds; Predicting growth and yield in the mid-south. 31st Annual Forestry Symposium. School of Forestry and Wildlife Management, Louisiana State University, Baton Rouge; pp. 119-139.

Clark, A., III., and R. C. Field.
1981. TBCP--A computer program that estimates total tree chips, sawlogs, pulpwood, and firewood from cruise summary data. Ga. For. Res. Pap. 21. Georgia Forestry Commission, Research Division; 14 pp.

Cost, N.D., and J.P. McClure.
1982. Multi-resource inventories: techniques for estimating biomass on a statewide basis. Research Paper SE-228. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 31 pp.

Flewelling, J.W., and L.V. Pienaar.
1981. Multiplicative regression with lognormal errors. For. Sci. 27:281-289.

Forbes, R.D., Ed.
1955. Forestry Handbook. New York: Ronald Press.

Husch, B.
1963. Forest mensuration and statistics. New York: Ronald Press; 464 pp.

Husch, B., C.I. Miller, and T.W. Beers.
1972. Forest mensuration. 2d Ed. New York: Ronald Press; 410 pp.

Husch, B., C.I. Miller, and T.W. Beers.
1982. Forest mensuration. 3d Ed. New York: Ronald Press; 402 pp.

Jacobs, M.W., and T. Cunia.
1980. Use of dummy variables to harmonize tree biomass tables. Can. J. For. Res. 10: 483-490.

Knight, H.A., and J.P. McClure.
1981. Multi-resource inventories--Forest biomass in South Carolina. Research Paper SE-230. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 27 pp.

Kozak, A.
1970. Method for ensuring additivity of biomass components by regression analysis. For. Chron. 46:402-404.

Meyer, H.A.
1953. Forest mensuration. State College, PA: Penns Valley Publishers; 357 pp.

Phillips, D.R. and J.R. Saucier.
1979. A test of prediction equations for estimating hardwood understory and total stand biomass. Georgia Forest Research Paper 7, Georgia Forestry Commission, Research Division; 8 pp.

Phillips, D.R. and J.R. Saucier.
1981. Cruising procedures for estimating total stand biomass. Georgia Forest Research Paper 14, Georgia Forestry Commission, Research Division; 7 pp.

Sproull, R.C., R.B. Parker, and W.L. Belvin.
1957. Whole tree harvesting. Forest Products J. 7:131-134.

Spurr, S.H.
1952. Forest inventory. New York: Ronald Press; 476 pp.

U.S. Department of Agriculture, Forest Service.
1981. Tree biomass - A state-of-the-art compilation. General Technical Report WO-33. Washington, DC: U.S. Department of Agriculture, Forest Service; 34 pp.

Yandle, D.O., and H.V. Wiant.
1982. Biomass estimates based on the simple power function--some calculation considerations. In Brown, T.B.; House, L.O., IV; Lund, H.G. eds. In-place resource inventories: Principles and practices: Proceedings of a national workshop; 1981 August 9-14; Orono, ME. Washington, DC: Society of American Foresters; pp. 350-354.

Young, H.E.
1964. The complete tree concept--A challenge and an opportunity. In: Proceedings, Society of American Foresters national meeting, 1964, September 27-30; Denver, CO. Washington, DC: Society of American Foresters; pp. 231-233.

Young, H.E.
1973. Growth, yield and inventory in terms of biomass. In: IUFRO Biomass Studies: Proceedings of the meeting or working party on mensuration of the forest biomass, S4.01 Mensuration, growth and yield; 1973 June 25-29; Nancy, France and 1973 August 20-24; Vancouver, BC, Canada. Orono, ME: University of Maine, College of Life Sciences and Agriculture; pp. 1-9.

Young, H.E.
1978a. Forest biomass inventory. In: McMillin, C.W. ed. Complete tree utilization of southern pine: Proceedings of a symposium; 1978 April 17-19; New Orleans, LA Madison, WI: Forest Products Research Society; 24-28 pp.

Young, H.E.
1978b. Forest biomass inventory; the basis for complete tree utilization. For. Prod. J. 28(5):38-41.

ECONOMICS OF BIOMASS--A NEW FOUND RESOURCE IN THE SOUTH[1]

J. MICHAEL VASIEVICH[2]

Abstract--Much biomass was once discarded in southern forests as waste. Now, forest managers recognize all fiber sources as potentially valuable commodities. Changes in forest production to recognize and recover biomass from forests have been caused by economic factors. Biomass is now worth something more than nothing. New systems have been developed to grow, measure, harvest, and utilize all biomass. The total biomass concept has affected every aspect of forest production from site preparation to harvesting to final product. As timber has become increasingly scarce in our economy, wood users have recovered more wood from each acre to control wood supply costs. Biomass has been found in the forest as a new timber resource. This trend toward greater productivity and more complete utilization is likely to continue and escalate.

Biomass in the form of tops, cull trees, and other unmerchantable material was once discarded in southern forests as waste. Now, forest managers recognize all fiber sources, including these, as potentially valuable commodities. Emphasis on maximum value yield from every managed acre is fast becoming the norm. New systems have been developed to measure, harvest, transport, and utilize biomass. Also, new methods of forest management have evolved to capitalize on the value of biomass. As timber has become increasingly scarce in our economy, foresters have turned to more intensive management and complete utilization of all available fiber on each site. This trend is likely to continue and escalate.

Changes in forest production to recognize and recover biomass from forests have been caused by economic factors. Biomass is now worth something more than nothing. We have discovered ways of harvesting it in a cost-effective manner and turning it into valuable products. The total biomass concept has filtered down to affect every aspect of forest production ranging from site preparation to harvesting. This paper systematically reviews the economic causes and effects of moving from systems which recognize traditional forest products to complete utilization of all forest biomass.

The primary motivating factor moving forestry toward more complete utilization has been the increased cost of timber to industry. Firms want to reduce wood costs and squeeze more products out of each tree, all in the name of profit.

The effects of more complete utilization on forest production have been many. Low quality stands that were unmanageable can now be converted to productive forestland economically. Harvesting operations have become more capital intensive and capture more volume per acre. More logs are moved as tree-lengths and merchandized at central woodyards rather than being bucked in the woods. Higher investments are being made in intensive site preparation, planting, and stand management, especially on the best sites. These investments aim to extract the highest dollar return from company owned lands for the purpose of securing a timber supply. Investments in intensive forestry are seen as cost effective substitutes for land ownership.

Timber is an important resource which makes up over one-quarter of the value of industrial raw materials in the United States, excluding fuels (USDA Forest Service 1982b). Annual production of timber in 1972 was valued at almost $3 billion on the stump. Harvesting doubled the value to almost $6.4 billion. By the time those trees were processed into products such as

---

1 Presented at the Fifth Annual Southern Forest Biomass Workshop, June 15-17, 1983, Charleston, SC.

2 The author is Research Forest Economist, USDA Forest Service, Southeastern Forest Experiment Station, Duke University, Durham, NC 27706.

lumber, plywood, and paper, the value increased eight times to over $23 billion.

Wood makes up a substantial portion of the cost of goods sold for the forest products industry. Other major costs include energy, capital or equipment, labor, and land. According to the recent USDA Forest Service report, An Analysis of the Timber Situation in the United States 1952-2030 (1982b), cost of delivered wood was 49 cents for a dollar of plywood, on the average with 1972 statistics. In the pulp and paper industry, wood costs were about 9 cents per dollar of output sold. Although this seems low, the value of paper is relatively high when compared to solid wood products. This figure would be much higher if wood costs were figured as a proportion of all costs rather than gross revenues. Since many pulp and paper manufacturing costs are fixed, such as plant and equipment, wood represents one of the major inputs which can be economized.

Trees have value because we manufacture useful products from them. Of course, they have intrinsic value for many other reasons as well. However, the stumpage value of a tree, or by extension a forest, depends on the market value of final products and the costs of converting timber into these economic goods. The forest products industry can do little to influence the final demand and market value for goods manufactured from wood. Like other businesses, they are mostly price takers and respond to market demand for their products. They produce whatever they can sell at prevailing prices. Therefore, profit depends largely on the control of the costs of production. Any management action which reduces costs without reducing output increases profit. Also, any action which increases production without increasing costs adds to profit. In general, any action for which the added value of the output is greater than added costs has a positive effect on profitability. This relatively simple "economic law" can be applied equally to growing timber, harvesting logs, and manufacturing forest products. In forestry, these actions are methods of reducing treatment costs and investments in more intensive management. In manufacturing, these actions include new equipment, processes, and products.

FOREST PRODUCT PRICES HAVE INCREASED FASTER THAN INFLATION

The wood products industry has been greatly influenced by increases in relative prices. In general, prices for primary wood products have increased much faster than prices for competing goods and faster than inflation. Price increases have been caused by cost-push inflation, rather than a demand-pull effect. Costs of manufacturing have increased, forcing a rise in product prices. Increases in product prices above competing materials reduce sales and profits. This problem has especially affected the solid wood sector. The 1979 producer price index for softwood lumber has increased 61 percent faster than other wholesale commodities since 1967. For softwood plywood, prices are up 37 percent over other goods. Pulp and paper products have also been affected. Woodpulp prices are up by 33 percent over inflation. Paper prices, however, have held relatively even with prices for other commodities. In contrast, prices for concrete, aluminum siding, brick, floor coverings, and other building materials have increased much less or declined in real price.

INDUSTRY HAS RESPONDED TO PRODUCT PRICE INCREASES

The forest products industry has responded in several ways to hold costs in line. One way has been to develop new products to expand markets and utilize wood that was considered waste in the past. In each case, a new product or process has increased the value of wood above its prior best use. Some of the new technological advances have included: production of lumber from small or short logs, molded parts from flaked material, new panel products such as particleboards, flakeboards and oriented strandboards, composite and reconstructed lumber products such as COM-PLY studs, laminated and resawn lumber, and laminated ties and timbers. One new process, the shaping lathe headrig, even squeezes 12 board feet or more of pallet lumber from a cubic foot of solid wood. These new methods have added markets for unmerchantable wood, especially low-grade hardwoods in the South (Stumbo 1981; Maloney, Huffaker, and Mahoney 1981). In the pulp and paper sector, increased attention has been given to using whole-tree chips as pulp furnish.

DEVELOPMENT OF WOOD ENERGY MARKETS

Another major cause of increased biomass utilization has been the increased use of wood for industrial fuel (Fege 1982, Doub 1979). Costs for conventional fuels such as oil, gas, and coal have increased greatly since the 1973 energy crisis. Forest products companies have traditionally been, and still are, major wood fuel users, but times have changed. Now, much of the waste wood is manufactured into higher value products and is unavailable for fuel. These companies replace this fuel source by recovering more low-grade volume from each acre and harvesting areas of low-quality material. In addition, other major industries have turned to wood as a primary fuel source. In North Carolina, at least 10 major brick manufacturers now fire their kilns with wood. Many textile mills and state institutions use wood as a primary fuel source. The list will surely grow in the near future for many southern states.

The development of wood energy has been a focal point for many public agencies in the past several years. The U.S. Department of Energy has

conducted a large R&D program on production of short-rotation woody biomass crops and biomass conversion technologies (Ranney and Cushman 1982; U.S. Dept. of Energy 1982). The USDA Forest Service has also devoted many research dollars to study biomass for energy. Several states have studied the implications of wood energy development and some are actively promoting the industrial use of wood (Pulaski and others n.d.; Lloyd 1975). States have concerns about the potential economic and environmental impacts of major energy wood markets. A symposium on the topic held at Dartmouth College in August 1981 (Hewett 1982) focused attention on the opportunities and problems of expanding use of wood for energy. Participants estimated that the amount of energy produced from wood probably would double by the year 2000 to about 4 to 5 quads (quadrillion Btu's), mostly in the South, Northeast, and Lake States. Symposium participants raised many issues. They cautioned against the possibility of serious abuse of the productive capability of forest lands. Premature harvest of stands for energy could limit production of more valuable products, especially on nonindustrial private lands. They also raised questions about overcutting the resource, environmental impacts, and declines in productivity caused by lack of forest management.

Energy use can be a contender in the competition for existing wood supplies at prevailing prices. In a companion report from Dartmouth, Hewett and Glidden (1982) estimated that a small industrial user in the South could use wood fuel profitably at surprisingly high prices. Wood was competitive with coal if the delivered price was less than $15.02 (1980 dollars) per green ton or about $42.06 per cord. When compared with gas, a user could pay up to $19.82 per green ton ($55.50 per cord). If oil was the alternative fuel, the maximum price that could be paid was $36.08 per green ton or $101.00 per delivered cord. Their estimates were based on the lifecycle costs of typical energy systems using current technology. Other studies have produced somewhat different numbers, but the message is clear, wood is an economic fuel.

WOOD ENERGY DEMAND AND PRICES ARE LIMITED

While these figures suggest that demand for energy wood can bid timber supplies away from traditional products, this is not likely for several reasons, especially in the South. These values are the maximum prices that a user could pay for an equivalent amount of energy and break even. They do not indicate the market prices which might prevail in an active energy wood market. Actual market transactions show that whole-tree chips suitable for energy are trading at prices at or below the delivered price for most roundwood products (Norris 1983). Typical delivered prices (FOB consuming mill) for fuel chips in May 1983 were $10 to $15 per green ton. This is only about half of the delivered pulpwood roundwood value in many regions. Resource statistics show that large supplies of low-grade material suitable for energy chips are available in the South (McClure, Saucier, and Biesterfeldt 1981). Many of these acres can be harvested at reasonable costs with whole-tree chipping operations. An energy market would make these sites profitable to harvest rather than costly to clear. Harvesting these sites to supply fuel chips is likely to remain more advantageous than diverting higher value roundwood into the burners.

Escalation of energy prices will likely be held in check by coal prices. Coal has been a relatively low cost and abundant fuel in the past and will remain so in the future. The United States has massive coal reserves which can be exploited without large increases in extraction costs. Therefore, even if oil and gas prices increase substantially, coal is not expected to rise as fast. Moderate coal prices will limit the demand and market price for wood fuel chips.

Another limitation to the expansion of wood energy markets is the high cost of converting combustion equipment to use wood. For many plants, the cost of gas or oil burners has already been paid. When retrofit costs are added to the fuel savings equation, wood fuel does not appear as favorable. Converting to wood is most profitable in several cases--when a new system is installed; if large supplies of wood fuel are available locally at low cost; when alternative fuel costs are very high; or if large amounts of energy are needed (Vasievich 1982). Accumulated fuel savings must offset the capital costs of equipment needed to handle, dry, and burn wood to be justified.

A third economic factor limiting the expansion of wood energy is the lack of existing wood fuel supply channels in many areas. Industries converting to wood must be assured a long-term uninterrupted supply of fuel at established prices. Some wood dealers are interested in supplying fuel chips in some areas. However, these supply markets are still in the formative stages. Standard supply offers seem to be 2- to 5-year contracts with fuel chip prices indexed to alternative fuels. In the same way consumers want a stable supply, dealers need a stable demand. They need a contract for 150 to 200 tons per day to justify each whole-tree chipping system. Capital cost for a single whole-tree chipping system can be $600,000 or more, plus operating expenses (Vasievich and Croll 1981). Industries may refrain from commitments to burn wood until supplies are easily obtainable and consumers are well informed about sources of supply.

TIMBER STUMPAGE PRICES ARE RISING

Timber stumpage prices have been rising faster than inflation due to the interaction of

supply and demand. This trend has held for at least three decades. Prices for southern pine sawtimber from National Forests have increased by more than 4 percent per year above inflation since 1967. Douglas fir prices from West Coast National Forests have gone up by nearly 10 percent per year above inflation. Similar but lower trends hold for sawtimber from private lands. Pulpwood prices have not risen as fast in many regions. The main cause of stumpage price increases has been industrial competition for limited timber resources. Some recent unpublished research by the author has suggested that an increase of the percentage of growing stock harvested each year by one percent would raise pulpwood stumpage prices by an average of $4 per cord in many southern regions. Increased competition for wood within a timbershed causes stumpage prices for all timber harvested to increase, rather than just prices for the extra volume cut. Therefore, a new mill or expanded capacity of an existing mill causes private market prices for all timber to increase. These higher wood costs erode profits and induce industrial wood consumers to look for ways to reduce wood costs.

MILLS WANT MINIMUM COST TIMBER SUPPLIES

One measure of the value of wood delivered to a mill is the cost of replacing it from some alternative source. Several sources of timber are available to industrial timber buyers. In most cases, wood can be drawn from company fee lands, other controlled lands, nonindustrial private lands, or from more efficient recovery of timber from harvested tracts. Companies harvest wood from the least costly source of supply while not diluting the strategic position of company-owned timber supplies. The option of increased recovery of previously unmerchantable material has been ranked as a high priority by many firms, especially on fee lands. Stumpage costs for this wood, or biomass, is very low, but recovery costs can be higher than for more conventional roundwood.

Recovery of unmerchantable woody material can be grouped into several classes for discussion purposes. Many stands are stocked with low-grade hardwoods or otherwise unmanageable stands. Whole-tree chipping systems are used to remove biomass in a clean cut. Wood is usually sorted for its best use and grade logs are bucked out at the log deck. Stumpage costs are about $1 to $2 per ton. Harvest costs range from about $10.00 to $15.00 per green ton for a conventional whole-tree chipping operation (Massey, McCollum, and Anderson 1981; Vasievich and Croll 1981; Stuart, Walbridge, and O'Hearn 1978). There are several significant economic consequences of these types of operations. Harvesting timber on these stands may not always be a revenue producing operation, but benefits accrue in other ways. One effect is that site preparation costs are reduced following a whole-tree chipping operation. This is often referred to as a site prep credit. In the case of fee lands, this can lead to a significant income tax benefit as well. Harvesting costs are normally expensed and offset income tax at the capital gains rate. Reforestation costs, including site preparation, are normally capitalized and recovered many years later through depletion. The net effect of reduced reforestation costs is a higher financial return on timber production. Also, the site is freed for production of a more valuable stand.

Another class of biomass recovery comes from more complete utilization of trees during routine final harvesting operations. This might be extended to complete utilization of all timber on a site. Here, stands are mostly merchantable pulpwood, sawtimber, and other conventional products. Harvesting is often conducted with tree-length logging methods using feller bunchers, grapple skidders, delimbing gates, and big-stick loaders. Truckloads of tree-length logs are delivered to the mill where the logs are converted to traditional sawlogs, veneer blocks, pulpwood sticks, and biomass. Substantial benefits occur from three sources--higher harvesting productivity, lower logging costs, and better product merchandising at the mill. This system is highly mechanized and expensive to operate, but produces high volumes efficiently. One drawback is that this system can not recover as much biomass as whole-tree chipping systems. Forest products companies have favored these harvesting methods because labor requirements are lower than other conventional systems and they are matched to well-stocked plantations of uniform timber. Some other benefits accrue, such as lower fire hazard and less costly site preparation.

Thinning seems to have returned to the forest management plans of many companies. The primary reason is the rapid rise in sawtimber prices over pulpwood prices. Companies justify the much higher costs of thinning by the lure of sawtimber price escalation. They also can improve investment return by accelerated cash flows from thinning. Removal of fusiform infected trees, reduced pine beetle hazard, and accelerated growth join higher sawtimber yields as arguments in support of active thinning programs. Although thinning can recover trees which might be lost to suppression mortality, it is not justifiable everywhere in the South. Thinning is most common in pine regions where stumpage prices are high. In many low price areas, few loggers are willing to spend their time on thinning operations.

There are problem areas where harvest of residuals or standing biomass is not economical with current technology. Tracts with low volumes per acre, less than 50 tons, or average stem size less than about six inches are not economically operable with whole-tree chippers. Also, small isolated tracts can not be harvested with these systems profitably. High costs for equipment setup require larger operating areas. In many

locations, whole-tree chip markets do not exist and loggers may not be available to cut private timber. No systems are currently available to economically collect and transport logging residues, but work is underway to develop equipment to meet this need.

FOREST MANAGEMENT IMPLICATIONS

Higher forest productivity and biomass recovery affects forest production. Sites are managed more intensively to get maximum wood volume and value. Timber has become too precious to be wasted. Higher investments are made on each acre to produce timber at the best financial return. Now, each forest management treatment must be silviculturally sound and economically viable. Some go as far as suggesting that silviculture has become the science of turning trees into silver.

Companies and profit-motivated investors require their timber investments to have a high and competitive rate of return. This requirement means that decisions on forestry investments are made using high discount rates for comparison with other investments. Higher discount rates bias decisions to favor quick payouts and short-term investments. Negative impacts which occur in the distant future, such as nutrient depletion, are almost insignificant when discounted at these high rates. Hence, short-term decisions may encourage declines in land productivity over the long run.

More intensive forestry often means that forests are less diverse biologically. This may reduce the traditional non-market values produced in forests such as wildlife habitat and aesthetic values. Nonindustrial private owners who prefer these forest outputs may resist the total biomass concept, and justifiably so.

Recognition of the timber resource as biomass requires foresters to change. Foresters need new skills and new tools to function in a biomass environment. Forests must be measured in different terms than before. Rather than volumes of sawlogs, chip-n-saw, and pulpwood, we must know more about the total volume and distribution of tree sizes. Terms such as sawlogs and chip-n-saw have relevance only at one point in time and depend on current technology. New kinds of yield models and volume tables are needed which are flexible and can show product volumes for changing measurement standards. Methods of buying and selling timber have changed, too. Timber sale contract provisions to encourage or allow complete utilization of all available biomass are becoming more common. Complete tree forestry requires more management by foresters to integrate harvesting and regeneration, to implement more intensive production, and to recognize and avert potential negative environmental impacts. Foresters must be able to assess the economic returns as well as the silvicultural and environmental effects of their total tree management actions.

INCOME TAXES AFFECT BIOMASS

Federal income tax effects have also stimulated higher production and recovery of biomass. Capital gains treatment for timber revenues has been a substantial forestry incentive for several decades. However, procedures for figuring taxes affect the level of forest management and biomass recovery, too. The costs of growing timber can be recovered through depletion when trees are harvested, but land costs can not be deducted unless the land is sold. Land costs do represent a cost of growing timber, though. A timber grower can get timber by two alternative investments, intensive forestry or extensive forestry. The extensive option requires more land but less capital in the recoverable timber basis. Intensive forestry substitutes management costs for land. Because landowners can recover timber production costs through depletion, amortization, or expensing, but not land costs, the more intensive forestry option is less expensive, other things being equal.

Tax regulations are often interpreted through revenue rulings issued by the Internal Revenue Service (USDA Forest Service 1982a). These rulings suggest that an incentive exists for recovery of as much residual volume as possible at the time trees are cut, rather than later. Rulings have held that the subsequent sale of tops, limbs, or stumps after timber harvesting does not qualify for capital gains treatment for timber producers. However, if these parts of the tree are removed at the time the trees are cut, then revenue from this biomass does qualify as a capital gain. Since taxes are a cost of producing wood, this effect reduces cost and encourages loggers to remove all products in one operation.

CONCLUSIONS

The economic causes and effects of the total biomass concept have been many. The move toward higher production and more complete utilization of forests has been caused by increases in the cost of timber supplies to industrial wood users. Technological advances in forest product manufacturing have allowed firms to expand the range of products they make from trees. Firms now recover as much timber volume and value per acre as possible to reduce wood costs. Wood energy demand and whole-tree chipping have created a major new market for low quality biomass. This market will develop and expand in response to rising prices for alternative fuels. Foresters need new tools and skills to manage forests for complete biomass recovery. Management actions to maximize timber volume and value must be silviculturally sound and must generate competitive financial returns. Higher returns requirements

for forestry favor short-term investments and discount future impacts on site productivity. Income tax incentives have favored one-pass complete tree utilization and encouraged increased productivity through more intensive forestry.

As timber has become increasingly scarce in our economy, more cost-effective ways to grow, harvest, and use it have emerged. This trend will continue as demands on limited forest resources increase. Perhaps one day, wood will become so valuable that even a sliver of wood will not go unused.

REFERENCES CITED

Doub, Richard L. (chairman), and others.
1979. Forest Biomass as an energy source. Study report of a task force. Society of American Foresters, Washington, DC. (Unnumbered Report)

Fege, Anne S.
1982. Hardwoods as an energy source. In: Proc., Society of American Foresters Annual Meeting, Cincinnati, Ohio, September 19-22, 1982.

Hewett, Charles E. (ed).
1982. Using wood to produce energy: priorities for public and private policy. The report of the fourth annual Dartmouth Symposium on Renewable Resources. The Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH. (Unnumbered Report)

Hewett, Charles E. and William T. Glidden, Jr.
1982. Market pressures to use wood as an energy resource: Current trends and a financial assessment. The Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH. (Unnumbered Report)

Lloyd, Sam (chairman).
1975. Governor's task force on wood as a source of energy, State of Vermont. Committee on Natural Resources, House of Representatives, State of Vermont. (Unnumbered Report)

McClure, Joe P., Joseph R. Saucier, and R. C. Biesterfeldt.
1981. Biomass in southeastern forests. USDA Forest Service, Res. Paper SE-227. Southeastern Forest Experiment Station, Asheville, NC.

Maloney, T. M., E. M. Huffaker, and R. J. Mahoney.
1981. Economic potential of dead softwood timber for fiber and wood based products. Washington State University, Department of Materials, Science and Engineering, Pullman, WA, Res. Report No. 81/57-17.

Massey, Joseph G., Michael P. McCollum, and Walter C. Anderson.
1981. Cost of whole-tree chips for energy--Louisiana case study. Forest Products Journal 31(2):34-38.

Norris, Frank W.
1983. Timber Mart-South. Timber Mart-South, Frank W. Norris (ed), Highlands, NC, Vol. 8(5).

Pulaski, Ellen C., Moustafa K. Karmous, Larry G. Jahn, and Phyllis B. Wainwright.
n.d. Wood energy information guide. Industrial Extension Service, School of Engineering, North Carolina State University at Raleigh.

Ranney, Jack W. and Janet H. Cushman.
1982. Short rotation woody crops program: annual progress report for 1981. Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 2000.

Stuart, William B., Thomas A. Walbridge, and Steven E. O'Hearn.
1978. Whole-tree chipping and conventional harvesting systems--Economic and productivity comparisons on a variety of stand types. Tappi 61(6):60-64.

Stumbo, Donald A. (ed).
1981. Utilization of low-grade southern hardwoods--feasibility studies of 36 enterprises. Madison, WI: Forest Products Research Society.

USDA Forest Service.
1982a. A guide to federal income tax for timber owners. USDA Forest Service, Agriculture Handbook Number 596.

USDA Forest Service.
1982b. An analysis of the timber situation in the United States 1952-2030. USDA Forest Service, Forest Resource Report Number 23.

U.S. Department of Energy.
1982. Project summaries; short rotation woody crops program. Oak Ridge National Laboratory, Environmental Sciences Division. (Unnumbered Report)

Vasievich, J. M. and P. M. Croll.
1981. An economic comparison of three systems for harvesting low-grade hardwood chips. In: Stumbo, Donald A. (ed). 1981. Utilization of low-grade southern hardwoods--feasibility studies of 36 enterprises. Madison, WI: Forest Products Research Society.

Vasievich, J. M.
1982. Six keys to profit from short-rotation biomass plantations. Text of a speech presented to the DOE Contractors Workshop, Athens, GA, August 19, 1982.

SESSION 2

BIOMASS INFORMATION - HOW IS IT BEING USED AND WHERE

Moderator: Noel D. Cost

BIOMASS INFORMATION AS BEING USED BY UNIVERSITIES[1/]

Charles A. Gresham[2/]

Abstract.--Biomass information is being used by southern and southeastern universities in their basic and applied research programs. Basic research projects include: 1. estimating the primary productivity of pine and hardwood ecosystems, 2. describing the cycling and storage of macro-nutrients in forests, 3. refining and improving statistical methods of sampling and analysis, and 4. quantifying the biomass from non-traditional sources like root systems, and exotic or non-commercial woody species. Applied research projects include evaluation of silvicultural practices with biomass methods, predicting the biomass of a variety of species and yields of several stand types, and determining the feasibility of short rotation silviculture for energy production.

This paper provides a general survey of biomass research of southern and southeastern universities in both the applied and basic areas. Examples from the published literature are included.

INTRODUCTION

The colleges and universities are involved in both basic and applied research projects that use the techniques and results of forest biomass estimation. At the 1972 Biomass Workshop, Frederick (1982) pointed out that differences in funding source, type of research mission, the participation in cooperative arrangements, and needs of the clientele being served all contribute to the uniqueness and scope of biomass projects. The atmosphere of academic freedom that is present on campuses also contributes to a diversity of needs and uses of biomass information, because each investigator has the opportunity to pursue research for which he or she can get support. Finally, university researchers did most of the earlier biomass work (Frederick 1982), thus there has been a longer time for 'evolution and diversification' of biomass projects. An example of this is the work of Harold Young at the University of Maine.

The purpose of this paper is to highlight the types of biomass related research that have been published by university investigators. This is not intended to be a review of the literature, but simply a survey of the range of biomass projects, with appropriate examples included. To facilitate presentation, the projects have been divided into either basic or applied research, with the knowledge that many projects can't be easily classified. Basic research projects include those projects dealing with ecosystem productivity, mineral pool and cycling rate estimation, refinement of analysis techniques, and the quantification of non-traditional sources of biomass. Applied research projects deal with the generation of biomass yield tables of various species or the use of biomass techniques to measure the response of a stand to a silvicultural treatment. The examples emphasize, but are not limited to, biomass studies conducted in the South.

BIOMASS AND PRODUCTIVITY OF ECOSYSTEMS

Plantations of southern pines have been widely studied by university researchers as well as Industrial and Forest Service researchers. Ku and Burton (1973) published biomass information for loblolly pine plantations on four Arkansas soils and Larsen et al. (1976) published biomass distribution data for old field loblolly

[1/]Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2/]Assistant Professor, The Belle W. Baruch Forest Science Institute of Clemson University, Georgetown, South Carolina, 29440.

pine plantations in southern Alabama. Nelson and Switzer (1975) published equations and tables which predict loblolly pine biomass, by tree component, for natural stands and plantations in Mississippi. Ralston (1973) published primary productivity estimates for a loblolly pine plantation in the piedmont of North Carolina. Earlier he published productivity data on older natural, loblolly pine stands (Ralston and Prince 1963). I have an ongoing study that will yield productivity data for a two-story loblolly pine stand and a similar longleaf pine stand in coastal South Carolina. This study includes biomass and productivity estimates of the tree, shrub and herb layers. Dry matter accumulation in a young longleaf pine plantation in the South Carolina sandhills was reported by Wiegert and Monk (1972). Nemeth (1973) published similar productivity estimates for young loblolly and slash pine plantations in coastal North Carolina. Working with a set of slash pine plantations in Florida that ranged from 2- to 34-years-old, Gholz and Fisher (1982) reported biomass and productivity estimates. Conner and Day (1976) estimated the productivity of a bald cypress-water tupelo stand in Louisiana.

There are published estimates of the biomass and productivity of several types of hardwood ecosystems in the South and Southeast. Dabel and Day (1977) estimated the aboveground biomass of a mixed hardwood community and a maple-gum community in the Dismal Swamp of Virginia. Their biomass estimates include both the woody and herbaceous vegetation. Working in a similar forest type, Schlesinger and Marks (1975) published above water biomass and productivity estimates for a cypress stand in the Okefenokee swamp. Piedmont hardwood stands in Georgia were studied by Monk et al. (1970) and aboveground biomass and productivity figures were reported. Hardwood stands in central Missouri were studied by Rochow (1973) who published biomass and productivity estimates for ground cover, saplings and trees. Ralston and Prince (1963) published productivity estimates for trees 1 inch dbh and greater in piedmont North Carolina hardwood stands. Concerning mountain hardwood stands, Day and Monk (1977) reported productivity estimates of stands at Cowetta in the Southern Appalachians, and Frederick et al. (1979) published area based biomass estimates for West Virginia Mountain hardwoods. Whittaker's (1966) work in the Smoky Mountains is among the earlier hardwood biomass reports. Finally, Gardner et al. (1982) published biomass tables for nine hardwood forest site types that occur in the South and Southeast and Frederick et al. (1979) have described the cooperative project to estimate biomass distribution in Coastal Plain hardwood forests.

MINERAL POOLS AND CYCLING RATES

Further laboratory processing of biomass samples to determine concentrations of macronutrients enables researchers to convert estimates of standing biomass to pools of macro-nutrients. This has been done by university researchers for a variety of forested ecosystems. The work of Smith, Nelson and Switzer (Switzer and Nelson 1972) covered nitrogen accumulation in young (0-20 years) loblolly pine plantations, in Mississippi. At Cowetta, in the North Carolina mountains, Day and McGinty (1975) reported the mineral cycling strategies of two species in a pine stand and two species in a hardwood stand. Mineral cycling was described for a mixed hardwood forest in Missouri by Rochow (1975), and in a cooperative study with the Forest Service, (Frederick et al. 1979) the biomass and nutrient distribution of hardwood forests in the southern coastal plain are being measured.

STATISTICAL METHODS

University researchers have contributed to the statistical aspects of biomass estimation, not only in the analysis of field data to construct predictive models, but also in the design phases of the project. For example, Cunia (1979a, 1979b) emphasized sample design in his discussion of the dependence of regression and properties of estimates on sample selection.

One aspect of biomass prediction that has received much journal discussion is the correction of a predicted biomass when a logarithmic regression model is used. This was pointed out by Zar (1968) and Hafley (1969), with approximate solutions being published later by other researchers. As an example, Yandle and Wiant (1981) presented some considerations of the problem when both Napierian logarithms and logarithms to the base 10 were used in the transformation. Flewelling and Pienaar (1981) provided correction factors and guidelines for their use and Wiant and Harner (1979) note aspects of calculating a percent bias of predicted values for an allometric model.

Another area of contribution by university researchers is the defining of errors in biomass prediction. Kozak (1970) discussed ways to insure additivity of predicted biomass components when compared to a single equation predicting total biomass and at the 1981 Biomass Workshop Bailey (1981) presented a discussion of error structure in double sampling, where the "observed" values in a regression model are predicted from another regression.

NON-TRADITIONAL SOURCES OF BIOMASS

This is somewhat of a catch-all category that was given renewed visability (and funding) by the recent energy crisis that lead to the energy-from-biomass concept. The projects in this category conducted by university personnel investigated either biomass from root systems which has not traditionally been harvested, or from plantations of fast growing species on a very short rotation.

Because of the labor involved there is not an abundance of information concerning root biomass.

Singer and Hutnik (1965) explained how water pressure could be used to reduce the labor involved in harvesting roots for weight determination. As part of the IBP project at Duke University, Kinerson (1972) estimated the root biomass in a 16-year-old loblolly pine plantation, and Box (1967) estimated the amount of root biomass in a 6-year-old loblolly pine plantation in Louisiana. Finally, Montague and Day (1980) reported lateral root biomass estimates for four stand types in the Great Dismal Swamp of Virginia.

Productivity of short rotation plantations has received much research attention. Steinbeck and May (1971) published yield figures for sycamore on rich clay sites in Georgia and Wittwer et al. (1978) presented productivity data for sycamore in Western Kentucky. Other examples include Carter and White (1974) who reported dry weight and nutrient yields from cottonwood plantations in an Alabama floodplain, Rockwood et al. (1980) who presented dry weight biomass production results for sand pine planted on a deep sand, and Geyer and Naughton (1981) who discussed short rotation culture of several hardwood species in Eastern Kansas.

Another aspect of biomass from non-traditional sources is the production of biomass from species generally considered non-commercial. My work (Gresham 1982) with loblolly-bay (Gordonia lasianthus) is an example as is research on Eucalyptus (Conde 1981) and the work with black locust (Pope and Rhodes 1981, Rowell and Carpenter 1983).

SILVICULTURAL TREATMENTS

The use of biomass techniques to evaluate silvicultural treatments is one of the two applied uses that university researchers have reported. White and Pritchett (1980) measure above- and below-ground biomass of 5-year-old loblolly pines in a flatwoods plantation that had fertilization and water table control treatments imposed. The effects of fertilization was also measured with biomass techniques by Haines and Sanderford (1976) for a 4-year-old loblolly plantation in the piedmont of North Carolina.

Another applied example is the work of Pope and Graney (1979) who reported significant differences in aboveground biomass among four half-sib families on the same soil type with the same site index.

BIOMASS YIELD TABLES

The other area of applied biomass research by university researchers has been in the development of yield functions and/or tables for various species.

Published reports of the biomass yield of loblolly pine boles can be found for plantations in the Piedmont of Virginia, Coastal Plain of Virginia, and the Coastal Plain of North Carolina (Burkhart et al. 1972); Georgia Piedmont (Burkhart and Clutter 1971), and the west Gulf Coastal Plain (Hicks and Lenhart 1972).

Equations for longleaf and slash pine in the North Florida pine flatwoods were reported by Swindel et al. 1982, and Reams et al. 1982 reported equations for aboveground components of slash pine in Mississippi.

Biomass equations have also been published for hardwood species. Wiant et al. 1977 published biomass equations for nine Appalachian hardwoods, Blackmon and Ralston (1968) presented equations for three hardwoods in the Piedmont of North Carolina and Reams et al. (1982) published equations for sweetgum in central Mississippi. These reports provide equations and/or tables to predict biomass of all or part of the tree as a function of dbh and height.

FUTURE RESEARCH

Now that we have surveyed what university biomass researchers have done and are doing, the next logical question is where should they direct their efforts in the future to use their resources most efficiently while providing a significant contribution? Of the six areas of biomass research discussed, I feel that investigators at universities should concentrate on determining the productivity of ecosystems, exploring the mineral cycling relationships in forested ecosystems and in improving and upgrading sampling and analysis techniques.

Productivity studies are necessary because varied demands on and uses of forested ecosystems require a knowledge of total production in order to determine the impact of the demands and uses. We must continue to view the forest as an ecosystem of trees, shrubs, herbs, animals and environmental interactions. Failure to monitor one of these components may lead to underestimating the cost of a manipulation of the forest.

Present at most major universities is the expertise to analyze plant, soil and water samples for nutrient concentration. Thus, when biomass samples are taken, little additional effort is required to subsample for mineral analysis. Nutrient concentration data coupled with the biomass results, will yield the framework for describing the cycling of these mineral nutrients, which is considered the key to forest productivity (Jorgensen et al. 1975).

Finally, university researchers, so inclined, should take advantage of the abundant computer resources and the on-campus mathematics and statistics faculty to explore alternative sampling and analysis techniques. Of the major groups doing biomass research, the universities are in the unique position of having these resources available and they should be used.

LITERATURE CITED

Bailey, R.L.
1981. Considerations of error structure in regression to predict biomass. In Proceedings .... 1981 Southern Forest Biomass Workshop (C.A. Gresham, ed.) p. 113-117. Baruch Forest Science Institute of Clemson University, Georgetown, S.C. 137p.

Blackmon, B.G. and C.W. Ralston.
1968. Dry weights of several piedmont hardwoods. Jor. of Forestry 66:418-420.

Box, B.H.
1967. A study of root extension and biomass in a six year old pine plantation in Southeast Louisiana. PhD Dissertation, School of Forestry, Duke University. 178p.

Burkhart, H.E. and J.L. Clutter.
1971. Green and dry weight yields for old-field loblolly pine plantations in the Georgia piedmont. Ga. For. Res. Council Rept. 22-4. 11p.

Burkhart, H.E., R.C. Parker, and R.G. Oderwald.
1972. Yields for natural stands of loblolly pine. Pub. FWS-2-72, Div. of Forestry and Wildlife Res., VPI&SU, Blacksburg, Va. 63p.

Carter, M.C. and E.H. White.
1971. Dry weight and nutrient accumulation in young stands of cottonwood (*Populus deltoides*). Circular 190, Ag. Expt. Stn., Auburn Univ., Auburn, Ala. 14p.

Conde, L.F.
1981. Measurements for tree biomass predictions. In Proceedings .... 1981 Southern Forest Biomass Workshop (C.A. Gresham, ed.) p. 82-93. Baruch Forest Science Institute of Clemson University, Georgetown, S.C. 137p.

Conner, W.H. and J.W. Day.
1976. Productivity and composition of a baldcypress-water tupelo site and bottomland hardwood site in a Louisiana swamp. Am. J. Bot. 63:1354-1364.

Cunia, T.
1979a. On tree biomass tables and regression: some statistical comments. In Forest Resource Inventories (W.E. Frayer, ed.) p. 629-642. Dept. of For. and Wood Sci., Colorado State Univ., Ft. Collins, Co. 1037p.

Cunia, T.
1979b. On sampling trees for biomass table construction: some statistical comments. In Forest Resource Inventories (W.E. Frayer, ed.) p. 643-664. Dept. of For. and Wood Sci., Colorado State Univ., Ft. Collins, Co. 1037p.

Dabel, C.V. and F.P. Day.
1977. Structural characteristics of four plant communities in the Great Dismal Swamp, Virginia. Bulletin Torrey Bot. Club. 104-352-360.

Day, F.P. and D.T. McGinty.
1975. Mineral cycling strategies of two deciduous and two evergreen tree species in a Southern Appalachian watershed. In Mineral cycling in Southeastern ecosystems (F.B. Howell, J.B. Gentry and M.H. Smith, eds.) p. 736-743. ERDA, Symposium Series CONF-740513, Nat. Tech. Info. Serv., U.S. Dept. Commerce, Springfield, Va. 898p.

Day, F.P. and C.D. Monk.
1977. Net primary production and phenology on a southern Appalachian watershed. Am. Jor. Bot. 64:1117-1125.

Flewelling, J.W. and L.V. Pienaar.
1981. Multiplicative regression with lognormal errors. For. Sci. 27:281-289.

Frederick, D.J., W.E. Gardner, A. Clark, D. Phillips and M. Williford.
1979. Biomass and nutrient distribution in hardwood forests of the Southern Coastal Plain. In Proceedings Impact of intensive harvesting on forest nutrient cycling (A.L. Leaf, ed.) p. 394. Northeast Forest Expt. Stn., Broomall, Pa. 421p.

Frederick, D.J., W.E. Gardner, P.L. Marsh, R.C. Kellison and B.B. Brenneman.
1979. Predicting weight yields of West Virginia mountain hardwoods. J. of For. 77:762-764, 776.

Frederick, D.J.
1982. Needs and future directions for biomass research and applications--a university perspective. In Proceedings of the 1982 Southern Forest Biomass Working Group Workshop (V.C. Baldwin and R.E. Lohrey, eds.) p. 125-128. Southern Forest Experiment Station, New Orleans, La. 131p.

Gardner, W.E., P. Marsh, R.C. Kellison and D.J. Frederick.
1982. Yields of natural hardwood stands in the Southeastern United States. N.C. State Hardwood Res. Cooperative Series No. 1, Raleigh, N.C. 64p.

Geyer, W.A. and G.G. Naughton.
1981. Short rotation forestry biomass yields and cost analysis in eastern Kansas. In Proceedings .... 1981 Southern Forest Biomass Workshop (C.A. Gresham, ed.) p. 7-19. Baruch Forest Science Institute of Clemson University, Georgetown, S.C. 137p.

Gholz, H.L. and R.F. Fisher.
1982. Organic matter production and distribution in slash pine plantations. Ecology 63:1827-1839.

Gresham, C.A.
1982. Biomass relations of Gordonia lasianthus, loblolly-bay. In Proceedings of the 1982 Southern Forest Biomass Working Group Workshop (V.C. Baldwin and R.E. Lohrey, eds.) p. 81-87. Southern Forest Expt. Stn., New Orleans, La. 131p.

Hafley, W.L.
1969. Calculation and miscalculation of the allometric equation reconsidered. Bioscience 19:974-983.

Haines, L.W. and S.G. Sanderford.
1976. Biomass response to fertilization in the Piedmont. In Proceedings 1975 Soc. of Am. Foresters Conf., Washington, D.C. p. 425-440.

Hicks, D.R. and J.D. Lenhart.
1972. Merchantable green weights for loblolly pine trees in old-field plantations in the interior West Gulf Coastal Plain. Texas For. Paper 16. S.F. Austin State Univ. Sch. of Forestry, Nacogdoches, Tx. 4p.

Jorgensen, J.R., C.G. Wells and L.J. Metz.
1975. The nutrient cycle: Key to continuous forest production. Jor. of For. 73:400-403.

Kinerson, R.S., Jr.
1972. Spatial distribution of root biomass. Memo Report 72-76. EDFB, Int. Biol. Prog. Triangle Res. Site, Duke Univ., Durham, N.C. 7p.

Kozak, A.
1970. Methods for ensuring additivity of biomass components by regression analysis. For. Chron. 46:402-404.

Ku, T.T. and J.D. Burton.
1973. Dry matter and minerals in loblolly pine plantations on four Arkansas soils. Ark. Acad. Sci. Proc. 27:21-24.

Larsen, H.S., M.C. Carter, J.W. Gooding and D.M. Hynik.
1976. Biomass and nitrogen distribution in four 13-year-old loblolly pine plantations in the Hilly Coastal Plain of Alabama. Can. J. For. Res. 6:187-194.

Monk, C.D., G.I. Child and S.A. Nicholson.
1970. Biomass, litter and leaf surface area estimates of an oak-hickory forest. Oikos 21:138-141.

Montague, K.A. and F.P. Day.
1980. Belowground biomass of four plant communities of the Great Dismal Swamp, Virginia. Am. Mid. Nat. 103:83-87.

Nelson, L.E. and G.L. Switzer.
1975. Estimating weights of loblolly pine trees and there components in natural stands and plantations in Central Mississippi. Miss. Agric. & For. Expt. Stn., Tech. Bulletin 73. 15p.

Nemeth, H.C.
1973. Dry matter production in young loblolly and slash pine plantations. Ecol. Monog. 43:21-41.

Pope, P.E. and D.L. Graney.
1979. Family differences influence the aboveground biomass of loblolly pine plantations. USDA, For. Serv. Res. Paper SO-155. 6p.

Pope, P.E. and J.D. Rhodes.
1981. Interaction of site, cultural practices, and tree species on dry matter accumulation in biomass plantations. In Proceedings of the First Biennial Southern Silvicultural Research Conference (J.P. Barnett, ed.) p. 249-255. Southern For. Expt. Stn., New Orleans, La. 375 p. 3.

Ralston, C.W. and A.B. Prince.
1963. Accumulation of dry matter and nutrients by pine and hardwood forests in the lower piedmont of North Carolina. In Forest-Soils Relationships in North America. p. 77-94. Oregon State University Press, Corvallis, Or.

Ralston, C.W.
1973. Annual primary productivity in a loblolly pine plantation. In IUFRO Biomass Studies (H.E. Young, ed.) p. 105-118. Coll. of Life Sci. and Ag. Univ. of Maine at Orono. 532p.

Reams, G.A., A.D. Sullivan, T.G. Matney and R.R. Stephens.
1982. Estimating aboveground biomass of slash pine and sweetgum. Miss. Ag. For. Expt. Stn. Tech. Bulle. 110. 11p.

Rochow, J.J.
1973. Estimates of above-ground biomass and primary productivity in a Missouri forest. Jor. of Ecology 62:567-577.

Rochow, J.J.
1975. Mineral nutrient pool and cycling in a Missouri Forest. Jor. of Ecol. 63:985-994.

Rockwood, D.L., L.F. Conde and R.H. Brendemuehl.
1980. Biomass production of closely spaced Choctawhatchee sand pines. USDA, For. Serv. Res. Note SE-293. 6p.

Rowell, C.E. and S.B. Carpenter.
1983. Black locust biomass prediction on Eastern Kentucky strip mines. So. Jor. Appl. Forestry. 7:27-31

Schlesinger, W.H. and P.L. Marks.
1975. Okenfenokee cypress swamp: forest biomass production and phytosiology. Bulletin of the Ecol. Soc. of Am. 56:28.

Singer, F.P. and R.J. Hutnik.
1965. Excavating roots with water pressure. Jor. of For. 63:37-38.

Steinbeck, K. and J.T. May.
1971. Productivity of very young Platanus occidentalis L. plantings grown at various spacings. In Forest Biomass Studied. p. 153-164. Coll. of Life Sci. and Ag., Univ. of Maine at Orono. 240p.

Swindel, B.F., L.F. Conde, J.E. Smith and C.A. Hollis, III.
1982. Green weights of major tree species in North Florida pine flatwoods. So. Jor. Appl. For. 6:74-78.

Switzer, G.L. and L.E. Nelson.
1972. Nutrient accumulation and cycling in loblolly pine (Pinus taeda L.) Plantation ecosystems: the first twenty years. Soil Sci. Am. Proc. 36:143-147.

White, E.H. and W.L. Pritchett.
1970. Water table control and fertilization for pine production in the flatwoods. Bull. 743, Inst. of Food and Agric. Sci., Univ. of Fla., Gainesville, Fl. 41p.

Whittaker, R.W.
1966. Forest dimensions and production in the Great Smoky Mountains. Ecology 47:103-121.

Wiant, H.V., C.E. Sheets, A. Colaninno, J.C. DeMoss and F. Castaneda.
1977. Tables and procedures for estimating weights of some Appalachian Hardwoods. Bulletin 659. W. Virginia Agric. and For. Expt. Stn. 36p.

Wiant, H.V. and E.J. Harner.
1979. Percent bias and standard error in logarithmic regression. Forest Science 25:167-168.

Wiegert, R.G. and C.D. Monk.
1972. Litter production and energy accumulation in three plantations of longleaf pine (Pinus palustris Mill.). Ecology 53:949-953.

Wittwer, R.F., R.H. King, J.M. Clayton and O.W. Hinton.
1978. Biomass yield of short rotation American sycamore as influenced by site, fertilizers, spacing and rotation age. So. Jor. Appl. For. 2:15-19.

Yandle, D.O. and H.V. Wiant, Jr.
1981. Biomass estimates based on the simple power function - some calculation considerations. In In-Place Resource Inventories: Principles and Practices (T.B. Brann, L.O. House, IV and H.G. Lund, eds.) p. 350-354. Soc. of Am. Foresters, Washington, D.C. 1101p.

Zar, J.H.
1968. Calculation and miscalculation of the allometric equation as a model in biological data. Bioscience 18:1118-1120.

THE DISTRIBUTION OF BIOMASS FROM THINNINGS IN APPALACHIAN HARDWOODS BY PRODUCT AND SOURCE[1/]

John E. Baumgras[2/]

Abstract.--Tree-weight equations and actual roundwood product volumes were used to estimate forest biomass yields from thinnings in 17 stands of Appalachian hardwoods, and to determine the distribution of biomass by source (bolewood, topwood, and submerchantable trees) and by product (sawlogs, sawbolts, pulpwood-fuelwood, and chips). Presents regression equations for predicting green-weight per-acre biomass yields from the amount of basal area removed per acre in thinning. Provides equations and tables for predicting the percent of biomass in each source and product component from the mean diameter of the trees removed in thinning.

INTRODUCTION

Commercial thinning in Appalachian hardwood stands presents an excellent opportunity to increase the future supply of quality hardwood products and to provide an immediate source of revenue to forest land owners. Thinnings in the poletimber and small-sawtimber stands that comprise a large segment of the Appalachian hardwood forests offer only limited volumes of valuable large-diameter sawlogs. Consequently, multiproduct harvesting often will be required to generate revenue sufficient to encourage thinning. By utilizing more of the available resource and by increasing the volume of wood that is channeled into high-value products, multiproduct harvesting can improve the prospects for commercial thinning.

Because of recent technological developments, primary hardwood products are no longer limited to large sawlogs and roundwood pulpwood. Small diameter sawlogs and sawbolts can be profitably processed for furniture stock or pallets (Reynolds and Gatchell 1971, 1982). Roundwood for home heating is a thinning product that has shown a tremendous increase in demand. Whole-tree chippers have also made it possible to process whole trees or tops and limbs into fiber or fuel. Because of whole-tree chipping, the aboveground biomass of all cut trees represents the potential yield from thinning. The economic feasibility of multiproduct thinning and the selection of efficient harvesting and marketing systems are therefore dependent on the total biomass and the product mix available from the stands to be thinned.

The objective of this study was to estimate the amount of whole-tree biomass available from thinnings and to determine the distribution of biomass by source and product components. To accomplish this, results from a study of roundwood-product volumes available from hardwood thinning (Baumgras 1981) were combined with recently published whole-tree and tree-component-weight equations. The application of tree-weight equations has been tested by Curtin and others (1980) and Phillips and Saucier (1979). Both tests found that tree-weight equations could be used to obtain reliable estimates of area biomass yields.

METHODS

Thinning plots were established in 17 stands of Appalachian hardwoods located in West Virginia and Virginia. These overstocked poletimber and small-sawtimber stands, aged 50 to 70 years, were growing on sites 60 to 90 (50-year basis). Two stands were northern hardwoods, seven were Allegheny hardwoods, seven were upland oak--yellow-poplar, and one stand was a mixture of upland and northern hardwoods.

[1/]Paper presented at Fifth Annual Southern Forest Biomass Workshop, Charleston, South Carolina, June 15-17, 1983.

[2/]Forest Products Technologist, USDA Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, Morgantown, West Virginia, 26505.

Each of the 113 plots (1/10- and 2/10-acre sample plots) was thinned from below to reduce stocking to the residual (B level) prescribed by the appropriate silvicultural guidelines (Leak et al. 1969, Roach 1977, Roach and Gingrich 1968). The diameter at breast height (dbh) and species were recorded for all trees (dbh $\geq$ 1.0 inch) marked for cutting. Trees varied a great deal from plot to plot because of the variety of stand conditions sampled, the amount of basal area removed, the number of trees cut per acre, and the mean dbh and height of the cut. The average and range of plot values for each of these cut-stand parameters are as follows:

Cut-stand parameter	Average	Range
Trees, dbh $\geq$ 1.0 inch:		
Basal area, ft^2/acre	58.0	24.4-128.3
Trees per acre	325.0	85-840
Mean dbh	6.0	3.2-8.8
Trees, dbh $\geq$ 5.0 inches:		
Basal area, ft^2/acre	48.2	15.2-118.2
Trees per acre	118.3	45-280
Mean dbh	8.8	6.2-14.4
Mean total height, dominant and codominant trees	77.4	57-102

All merchantable trees (dbh $\geq$ 5.0 inches) marked for removal were felled. Total height and height to a 4.0-inch-dob (diameter outside bark) top were measured, and the entire bole section to a 4.0-inch dob was marked off into sawlogs, sawbolts, and pulpwood-fuelwood. Sawlogs, which were selected first, met or exceeded the minimum requirements for Factory Grade 3 sawlogs according to the USDA Forest Service's standard hardwood sawlog grading system (Rast et al. 1973). Sawbolts were bole sections that failed to meet the minimum sawlog requirements but would yield at least one sound square edge 4- by 4-inch cant (National Hardwood Lumber Association 1974). All remaining nonsawable bole sections (dob $\geq$ 4.0 inches) were placed in the combined pulpwood-fuelwood category. The cubic volume of wood and bark was calculated for each roundwood product by using Smalian's formula. Total bole volume was calculated by summing the volumes of all roundwood products.

From the dbh, height, and species information collected from each plot, the aboveground biomass available from each cut tree, excluding foliage and stumpwood, was predicted using weight equations for whole trees. The whole-tree weight of each submerchantable tree (1.0 inch $\leq$ dbh < 5.0 inches) was predicted from dbh by using the equation for small hardwood trees published by Wartluft (1977). Equations by Brenneman and Daniels (1982) were used to estimate whole-tree and tree-component weights of merchantable trees of the following species: white ash (*Fraxinus americana*), basswood (*Tilia americana*), beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), sweet birch (*Betula lenta*), red maple (*Acer rubrum*), and sugar maple (*Acer saccharum*). For all oaks (*Quercus alba*, *Quercus prinus*, *Quercus rubra*), yellow-poplar (*Liriodendron tulipifera*), hickories (*Carya* sp.), and black cherry (*Prunus serotina*), merchantable tree-weight estimates were based on equations by Wiant and others (1979). For the few remaining tree species sampled, Brenneman's hardwood tree-weight equation was used.

Brenneman's equations use dbh and height to a 4.0-inch-dob top to predict the green weight of the whole tree and the bole to a 4.0-inch-dob top. The green weight of the topwood was estimated by subtracting bole weight from whole-tree weight. Wiant's equations use dbh and total height to predict whole-tree weight, bole weight to a 4.0 inch dob, and top weight. To obtain additive component weights when using Wiant's equations, both the bole-weight and top-weight estimates were divided by the sum of these two estimates, and the resulting ratios were multiplied by weight estimates for the whole tree.

The green weight of the roundwood products (sawlogs, sawbolts, pulpwood-fuelwood) in the bole of each merchantable tree was estimated by multiplying the predicted bole weight by the ratio of product volume to total bole volume. Since the bole volume was equal to the sum of the product volumes, the product weight estimates were additive and directly proportional to the actual product volume of each tree.

Converting total-plot yields to per-acre values provided estimates of the whole-tree biomass thinned from each plot and gave the breakdown of this biomass by source and product components, all expressed in green tons per acre. The relationship between source and product components is as follows:

Source of Biomass	Potential Products
Submerchantable trees →	Chips
Merchantable trees	
→ Topwood →	Chips
→ Bolewood →	Sawlogs, Sawbolts, Pulpwood-fuelwood

RESULTS

Total Biomass Yields

The estimated total aboveground biomass yields from all plots averaged 65 green tons per acre and ranged from 22 to 164 green tons per acre. Differences between plots with respect to species composition and the diameter and total height of the cut trees contributed to the variation in plot biomass yields. Most of this variation, however, can be attributed to the amount of basal area removed in thinning. The relationship between the estimated plot biomass yields and the basal area removed from each plot was developed through regression analysis. The results of this analysis are:

Equation	R^2	$S_{y.x}$	F	Prob.>F
GW1=1.225(B1)-6.05	0.82	9.79	504.3	0.0001
GW5=1.355(B5)-7.23	0.90	7.66	949.1	0.0001

Where:

GW1 = total aboveground biomass available from all trees 1.0 inch dbh and larger, green tons per acre

B1 = basal area removed in trees 1.0 inch dbh and larger, ft^2 per acre

GW5 = total aboveground biomass available from all trees 5.0 inches dbh and larger, green tons per acre

B5 = basal area removed in trees 5.0 inches dbh and larger, ft^2 per acre

These regression coefficients are very similar to conversion factors developed from actual tree weights in a study by Stuart and others (1980). They found that 11 to 12 green tons of biomass could be expected per 10 ft^2 of basal area removed in Appalachian hardwood stands.

DISTRIBUTION OF BIOMASS

To evaluate the distribution of whole-tree biomass between the source and product components, the green weights of all biomass components from each plot were converted to relative yields by expressing them as a percentage of the biomass yield for the total plot. These relative plot yields could then be compared or combined so that each plot received equal weighting, even though total plot yields differed greatly.

The average and range of relative plot yields by biomass source and potential product are:

	Average	Range
	---Percent---	
Source		
Bolewood, dob ≥ 4.0 inches	67.7	41.3-83.2
Topwood	20.2	11.5-28.9
Submerchantable trees	12.1	1.5-36.2
Total	100.0	
Product		
Sawlogs	21.8	0.0-62.4
Sawbolts	17.7	4.4-37.3
Pulpwood-fuelwood	28.2	10.5-47.0
Chips (topwood plus submerchantable trees)	32.3	16.8-58.7
Total	100.0	

These results show that for all plots, 67.7 percent of the biomass was from the bolewood of merchantable trees. This wood can be harvested by conventional roundwood logging systems. The remaining 32.3 percent can generally be harvested only as chips or left in the woods as residue from topwood and submerchantable trees.

The percent of biomass in each product category represents the average product mix from all thinning plots. Sawlogs were 21.8 percent of the available biomass; sawbolts 17.7 percent. Combining the average sawlog and sawbolt mix shows that approximately 40 percent of the biomass was in sawable roundwood. The pulpwood-fuelwood mix plus the chips from topwood and submerchantable trees shows that approximately 60 percent of the biomass was suitable only for fiber or fuel.

The wide range of relative-plot-yield values demonstrates the variation found in the distribution of biomass by source and product. For example, the percent of biomass from bolewood ranged from 41.3 to 83.2 percent, and the percent in sawlogs ranged from 0 to 62.4 percent. This variation reflects the diversity of the stands sampled, particularly the differences in the diameter of the trees removed from each plot. Regression analysis was used to quantify the relationship between the mean dbh (dbh of the tree of average basal area) of the merchantable trees cut and the percent of biomass in each component. These equations provided the estimates of the expected component mix shown in Tables 1 and 2.

Table 1.--The distribution of biomass among source components by mean dbh of cut trees.

Mean dbh[1/] (inches)	Biomass component: Bolewood ≥ 4.0" dob	Topwood	Submerchantable trees[2/]
	------(Percent)------		
6.5	48.1	23.0	28.9
7.0	56.4	21.0	22.6
7.5	62.3	20.0	17.7
8.0	66.5	19.6	13.9
8.5	69.4	19.5	11.1
9.0	71.5	19.6	8.9
9.5	73.0	19.8	7.2
10.0	74.0	20.1	5.9
10.5	74.8	20.3	4.9
11.0	75.3	20.6	4.1
11.5	75.6	20.8	3.6
12.0	75.9	21.0	3.1

1/Cut trees (dbh ≥ 5.0 inches)

2/Whole tree (5.0 inches > dbh ≥ 1.0 inch)

The results from this analysis show that as the mean dbh of the merchantable trees increased from 6.5 to 12 inches, the percent of biomass in the bolewood of merchantable trees increased from 48.1 to 75.9 percent while the percent from submerchantable trees decreased from 28.9 to 3.1 percent (Table 1). The percent of biomass in topwood remained relatively constant at approximately 20 percent (Table 1).

By comparison, when Brenneman and others (1978) sampled 10 stands of Appalachian hardwoods, they found 75.9 percent of the total biomass in bolewood, 19.5 percent in topwood, and 4.6 percent

Table 2.--The distribution of biomass among product components, by mean dbh of cut trees

Mean dbh[1/] (inches)	Potential Products			
	Sawlogs	Sawbolts	Pulpwood-fuelwood	Chips[2/]
	----------(Percent)----------			
6.5	0.2	10.9	37.0	51.9
7.0	6.7	15.4	34.3	43.6
7.5	12.5	17.9	31.9	37.7
8.0	17.5	19.1	29.9	33.5
8.5	21.8	19.4	28.2	30.6
9.0	25.6	19.2	26.7	28.5
9.5	28.9	18.7	25.4	27.0
10.0	31.7	18.0	24.3	26.0
10.5	34.3	17.2	23.3	25.2
11.0	36.4	16.4	22.5	24.7
11.5	38.3	15.5	21.8	24.4
12.0	40.0	14.8	21.1	24.1

[1/]Cut trees (dbh $\geq$ 5.0 inches)

[2/]Chips = biomass available only by chipping submerchantable trees and tops of merchantable trees

in submerchantable trees. The mean dbh of the merchantable trees in Brenneman's sample was 9.4 inches. The results in Table 1 at 9.5 inches compare favorably with Brenneman's findings.

The increase from 6.5 inches to 12.0 inches in the mean dbh of the merchantable trees also has a significant effect on the product mix. The proportion of biomass in sawlogs increased from 0.2 to 40.0 percent, as roundwood pulpwood decreased from 37.0 to 21.1 percent (Table 2). The relative amount of chips from topwood and submerchantable trees also decreased from 51.9 percent at 6.5 inches, to 24.1 percent at 12.0 inches (Table 2). The sawbolt mix increased from 10.9 percent at 6.5 inches to 19.4 percent at 8.5 inches, and then decreased to 14.8 percent at 12.0 inches.

PRODUCT AND COMPONENT MIX PREDICTORS

The regression models developed for Tables 1 and 2 follow. The application of these models should be limited to thinnings in stands with similar species composition to those sampled, where the mean dbh of the cut trees is not less than 6.5 inches nor more than 12.0 inches.

Symbols used in these models are:

X = the mean dbh of the merchantable trees to be removed in thinning. This can be calculated from B5 (basal area, ft^2 per acre of all cut trees $\geq$ 5.0 inches dbh), and T5 (number of trees cut per acre, dbh $\geq$ 5.0 inches) by mean dbh = $(183.35\ B5/T5)^{1/2}$

PBW = percent of total biomass in bolewood of trees, dbh $\geq$ 5.0 inches

PSM = percent of total biomass in submerchantable trees, 5.0 inches > dbh $\geq$ 1.0 inch

PTW = percent of total biomass in topwood of trees, dbh $\geq$ 5.0 inches

PSL = percent of total biomass in Factory Grade sawlogs, Grade 3 or Better

PSB = percent of total biomass in sawbolts

PPF = percent of total biomass in pulpwood-fuelwood, dob $\geq$ 4.0 inches

PCH = percent of total biomass harvestable only as chips from topwood and submerchantable trees

For the model $Y = a\ [1 + (be^{-cx})]$, the coefficients and statistics are:

Y	Coefficients a	b	c	Statistics R^2	Standard deviation of estimate
PBW	76.5241	-33.7360	0.6936	0.76	4.29
PSM	1.6832	519.8057	0.5336	0.64	5.30
PSL	51.2148	-5.9760	0.2755	0.72	6.62
PPF	17.3285	7.9059	0.2984	0.36	5.62
PCH	23.4759	109.9688	0.6936	0.76	4.29

The variables PTW and PSB were estimated as residuals of the sum of other components:

	R^2	Standard deviation of estimate
PTW = 100 - (PBW + PSM)	0.06	3.36
PSB = 100 - (PSL + PPF + PCH)	0.16	5.39

DISCUSSION

The results of this study show that hardwood thinning can provide large quantities of biomass for sawn products, fiber, or fuel. However, the variation found in both the total yield and the distribution of biomass indicates that opportunities to use biomass can change significantly from stand to stand. Therefore, the relationships between stand parameters and biomass yields should be a major consideration when stands are marked for thinning, when utilization and marketing alternatives are evaluated, or when harvesting systems are selected.

Estimated aboveground forest biomass yields from thinning averaged 65 green tons per acre and were closely correlated with the amount of basal area removed. As a result, the basal area to be removed in thinning can be used to estimate whole-tree biomass yields. Other methods of estimating biomass yields from tree or stand data are described by Wiant and others (1977), Monteith (1979), and Stuart and others (1980).

The relationship between the dbh of the cut trees and the distribution of biomass by product and source (Tables 1 and 2) provides an opportunity before thinning to evaluate alternatives for biomass use. For example, the degree of utilization afforded by conventional roundwood harvesting systems is shown by the percent of biomass in the bolewood (Table 1). At 6.5 inches mean dbh, less than half of the available biomass can be harvested as bolewood. To harvest the remaining biomass would require the use of a whole-tree chipper. As the mean dbh approaches 12.0 inches, three-fourths of the biomass can be harvested in bolewood.

If whole trees are utilized, but cutting is limited to trees 5.0 inches dbh and larger, the percent of total biomass harvested would equal the sum of the bolewood and topwood values shown in Table 1. When the mean dbh exceeds 9.0 inches, these two components are more than 90 percent of the available biomass. The remaining component, submerchantable trees, is a relatively minor contributor to the biomass supply once the mean dbh exceeds 8 or 9 inches.

Because the row values in Table 2 are additive, combining product mix values can provide an evaluation of various utilization alternatives. For example, when whole-tree chipping is used at the woods landing, the pulpwood-fuelwood component would probably be chipped along with the topwood and submerchantable trees. With a sawlog or sawbolt market, these two products could be sorted before chipping and marketed as sawable roundwood to increase revenues from thinning. If the mean dbh of the cut trees is 9.0 inches, adding pulpwood-fuelwood to the chip mix puts 55.2 percent of the biomass into chips, and 44.8 percent into sawable roundwood. Without a sawbolt market, that component would also go into chips resulting in 74.4 percent chips and 25.6 percent sawlogs (Table 2).

LITERATURE CITED

Baumgras, John E.
1981. The yield of sawbolts and sawlogs from thinnings in Appalachian hardwoods. In: Proceedings, 9th Annual Hardwood Symposium of the Hardwood Research Council, Asheville, NC; 1981 May 25-28; Pipestem, WV. p. 46-52.

Brenneman, B. B. and Richard F. Daniels.
1982. A case study, with alternatives, for calculating biomass yield. In: Proceedings Southern Forest Biomass Working Group Workshop, Alexandria, LA; 1982 June 16-18; Baton Rouge, LA. p. 105-110.

Brenneman, B. B.; D. J. Frederick; W. E. Gardner; L. H. Schoenofen; and P. L. Marsh.
1978. Biomass of species and stands of West Virginia hardwoods. In: Proceedings, Central Hardwood Forest Conference II; 1978 November 16; West Lafayette, IN, Purdue University. p. 159-170.

Curtin, Dennis T.; Robert T. Brooks, Jr.; and John C. Rennie.
1980. Testing biomass prediction equations with conventional cruise and whole-tree harvesting techniques. Tech. Note B41. Norris, TN: Tennessee Valley Authority; 27 p.

Leak, William B.; Dale S. Solomon; and Stanley M. Filip.
1969. A silvicultural guide for northern hardwoods in the Northeast. Res. Pap. NE-143. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 34 p.

Monteith, D. B.
1979. Whole-tree weight tables for New York. AFRI Res. Pap. No. 40, Applied Forestry Research Institute, State University of NY. 69 p.

National Hardwood Lumber Association.
1974. Rules for the measurement of hardwood and cypress lumber. National Hardwood Lumber Assoc., Chicago, IL. 115 p.

Phillips, Douglas R. and Joseph R. Saucier.
1979. A test of prediction equations for estimating hardwood understory and total stand biomass. GA. For. Res. Pap. No. 7. Georgia Forestry Commission, Macon, GA. 7 p.

Rast, E. D.; David L. Sonderman; and Glenn L. Gammon.
1973. A guide to hardwood log grading. Gen. Tech. Rep. NE-1. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 32 p.

Reynolds, Hugh W. and Charles J. Gatchell.
1971. The SHOLO mill: return on investment versus mill design. Res. Pap. NE-187. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 46 p.

Reynolds, Hugh W. and Charles J. Gatchell.
1982. New technology for hardwood utilization: System 6. Res. Pap. NE-504. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 8 p.

Roach, Benjamin A.
1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. Res. Pap. NE-373. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 30 p.

Roach, Benjamin A. and Samuel F. Gingrich.
1968. Even-aged silviculture for upland central hardwoods. U.S. Department of Agriculture, Agric. Handb. 355. 39 p.

Stuart, W. B.; R. G. Oderwald; and E. C. Ford.
1980. Prism cruising coefficients for Appalachian hardwoods biomass. South. J. Appl. For. 4(1):25-26.

Wartluft, Jeffrey L.
1977. Weights of small Appalachian hardwood trees and components. Res. Pap. NE-366. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 4 p.

Wiant, Harry V., Jr.; Froylan Castaneda; Carter E. Sheetz; Andrew Colaninno ; and James C. Demoss.
1979. Equations for predicting weights of some Appalachian hardwoods. WV For. Note No. 7. Morgantown, WV. p. 21-26.

Wiant, Harry V., Jr.; C. E. Sheetz; A. Colaninno; J. C. Demoss; and F. Castaneda.
1977. Tables and procedures for estimating weights of some Appalachian hardwoods. WV Univ. Agric. Exp. Stn. Bull. 659T. Morgantown, WV. 36 p.

CONVERTING BROAD-SCALE TIMBER INVENTORIES TO BIOMASS[1/]

by

Joe P. McClure[2/]

Abstract.--Broad-scale timber inventories have been conducted on a State-by-State basis since 1930, but only since passage of the RPA in 1974 have multiresource and multipurpose inventories been designed to include forest biomass as an inventory objective. Forest Survey, being both a consumer and a supplier of forest biomass data, has made rapid advances in the measurement and use of forest biomass information. Since 1976 the Forest Survey Unit of the Southeastern Forest Experiment Station has adapted and used biomass inventory techniques to expand the usefulness of statewide timber inventories and by doing so has become a major user of forest biomass research results. Forest Survey biomass data have been used in a variety of resource and evaluation studies and a number of research papers dealing with forest biomass have been published for individual States and the entire Southeastern region.

INTRODUCTION

Since 1974 workers in Forest Inventory and Analysis Units have been adjusting to an increasing requirement to expand timber inventories into multiresource inventories of forests. It soon became clear that biomass would be a key variable in these inventories. Biomass is of great interest as an alternate energy source, and it is becoming increasingly important to forest products manufacturers who buy and sell timber by weight.

In this paper I give historical background on statewide forest inventories and show what adjustments were made to express inventories in terms of biomass. I also show ways in which the forest biomass data gathered in the Southeast are being applied.

HISTORICAL BACKGROUND

In 1928, Congress passed the McSweeney-McNary Forest Research Act authorizing the Secretary of Agriculture to make and keep current a comprehensive survey of the Nation's timber resources. As a result of that legislation, the Forest Service organized the nationwide Forest Survey. The initial broad-scale timber inventories conducted under authority of the Act were designed to measure the extent and condition of the Nation's commercial forest land and to measure the volume of growing stock.

In the early days of the Forest Survey two key standards were established to insure compatibility and consistency from State to State. First, uniform criteria and definitions for classifying and measuring commercial forest land were developed. Second, standard procedures were established for identifying and measuring the merchantable volume in growing-stock trees. Merchantability standards were based on utilization practices and industrial needs of the time, and Forest Survey results were appropriately expressed in acres, cords, and board feet. To preserve an accurate and consistent measure of inventory trends, the basic criteria, definitions, and standards for measuring commercial forest land and growing-stock volume have remained essentially unchanged for over 50 years.

Additional classifications and measurements have been added over the years to keep abreast of changing utilization practices and satisfy

---

1/Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

2/The author is Project Leader of Forest Survey-Forest Inventory and Analysis Research Work Unit of the Southeastern Forest Experiment Station, Asheville, North Carolina.

current information needs. This strategy has permitted the nationwide Forest Survey to meet its multiple objectives. Each State survey is designed to be consistent with past surveys, to be compatible with other Survey projects throughout the Nation, and to gather and process the inventory data in a manner most likely to satisfy current information needs.

The most recent and one of the most significant expansions in Forest Survey data collection and evaluation activities involves a shift from timber-oriented forest inventories to multiresource inventories, including the evaluation of forest biomass. This new and greatly expanded role for Forest Survey was authorized by the 1974 RPA and the 1978 Renewable Resources Research Act. The 1978 Forest Survey of South Carolina was the first statewide multiresource inventory designed to measure forest biomass. The 1980 Florida multiresource inventory was further expanded to measure biomass on both forest and nonforest land on a statewide basis. A subsequent 1982 multiresource inventory of Georgia and an ongoing inventory in North Carolina are continuing to provide a comprehensive measure of both forest and nonforest woody biomass.

FOREST SURVEY EVALUATION SUBJECTS

Traditional timber inventories conducted in the United States since 1930 are rather complex and poorly understood by most foresters. The modern multiresource inventories now being conducted by the various Forest Survey projects can be almost overwhelming. In an effort to keep the multiresource inventory activities better organized, we developed a concept to break the inventory into categories called evaluation subjects. This breakdown makes it somewhat easier to think through the various steps in the inventory process. It also helps organize cooperative research with specialists and experts in various areas of forestry. The 16 evaluation subjects listed below are used to plan, conduct, analyze, and publish multiresource inventories and to maintain order and balance throughout all phases of the work.

EVALUATION SUBJECTS

1.	Land base	9.	Biomass
2.	Timber	10.	Ecology
3.	Wildlife	11.	Botany
4.	Range	12.	Diversity
5.	Recreation	13.	Protection
6.	Soils	14.	Use interactions
7.	Water	15.	Information management
8.	Fisheries	16.	Techniques research

Each broad Forest Survey evaluation subject can be treated as a separate functional inventory for planning and evaluation purposes, but the multiresource inventory design combines them into a single, efficient system. The multiresource approach also provides maximum opportunity for evaluating use interactions, since all data are gathered at the same time and at the same locations. Independent functional inventories lack this advantage. The next logical step in designing a multiresource inventory is to consider each evaluation subject separately and focus on specific information needs. From these needs arise the individual data items that must be recorded at each field sample location.

BIOMASS - INFORMATION NEEDS

Within each broad Forest Survey evaluation subject we have identified specific information needs. These information needs may be of a general nature but they should represent the full range of information expected from the completed inventory. This phase of inventory planning can be viewed as sorting. Some types of information are excluded because they are either not suited to broad-scale inventories, are excessively expensive to gather, or would be a duplication of information available from other sources. While not necessarily all-inclusive, the listing of information needs reminds us of key categories of information we eventually want to extract and analyze. During the planning stage of the inventory the various information needs are used to select the sampling schemes to be used, identify specific data items, prepare field procedures, write specifications, develop definitions, and establish coding systems. For example, under the evaluation subject labeled Biomass, we have listed the following information needs:

- Merchantable growing stock
- Merchantable portion of cull trees
- Stumps
- Tops and limbs
- Dead trees
- Saplings
- Seedlings
- Bark
- Foliage; leaves, twigs, and branches
- Other vegetation; shrubs, vines, grasses, and forbs
- Vegetation on nonforest land; agriculture, urban, etc.
- Conversions; volume to weight factors
- Conversions; weight to energy units
- Conversions; weight to nutrient values
- Conversions; weight to chemical content
- Conversions; weight to wildflife food values

FOREST SURVEY BIOMASS MODEL

A forest inventory can be rather simple, involving the collection and processing of very little data for a single purpose, or it can be very complex, involving the collection of large amounts of data for many purposes. Whether large or small, however, a well-designed inventory must

have either an implied or explicit inventory model to be used (1) as a guide in organizing the planning, collection, processing, and analysis of the project, (2) as a means of assuring that all inventory components are accounted for, (3) to ensure that adequate coordination is maintained throughout all phases of the inventory, and (4) to ensure that all inventory objectives are met.

In the nationwide Forest Survey the basic inventory model is described in considerable detail in the Forest Service Forest Survey Handbook, which contains chapters dealing with objectives, definitions, procedures, codes, and national standard tables. This national forest inventory model was generally adequate for traditional timber inventories but not for modern multiresource and multipurpose inventories. Therefore, an interim regional model was developed to deal with nontimber forest resources such as wildlife, recreation, range, hydrology, and biomass. The following model illustrates the approach being used to inventory biomass in the Southeast and shows that, although our primary interest is still with trees growing on commercial forest land, we are expanding our inventory effort to include both noncommercial forest land and woody vegetation occurring on nonforest land.

GENERAL BIOMASS MODEL

Commercial Forest Land

- Sawtimber trees
  - Stump
  - Sawlog portion
  - Upper stem
  - Top and limbs
  - Foliage
- Poletimber trees
  - Stump
  - Bole
  - Top and limbs
  - Foliage
- Cull trees
  - Stump
  - Bole
  - Top and limbs
  - Foliage
- Saplings
  - Wood and bark
  - Foliage
- Other vegetation
  - Seedlings
  - Shrubs
  - Vines
  - Grasses
  - Forbs

Noncommercial Forest Land

- All live trees
  - Wood and bark
  - Foliage
- Other vegetation
  - Woody
  - Herbaceous

Nonforest Land

- All trees
  - Wood and bark
  - Foliage
- Other vegetation
  - Woody
  - Herbaceous

CONVERTING FOREST SURVEY TO BIOMASS

Once the decision has been reached to include biomass as an evaluation subject in multiresource inventories in the Southeast, the biomass information needs were identified and a biomass model was developed. Then converting forest survey to biomass was a matter of (1) developing biomass sampling procedures, (2) acquiring weight equations for Southeastern tree species, (3) modifying inventory field procedures for collecting special biomass data, and (4) reprocessing the existing Southeastern inventory database in terms of green weight.

Improving Inventory Procedures

Each forest inventory started in the Southeast since 1976 has had increasingly greater emphasis placed on sampling methods, classifications, and measurements needed for evaluating the forest biomass resource and the amount of woody biomass on nonforest lands. The 1978 South Carolina multiresource inventory was improved by adding measurements of total heights of sapling-size trees and procedures to profile the structure and composition of total vegetation and aboveground biomass. Biomass data collection in the 1980 Florida inventory was expanded into noncommercial forest land and nonforest land. The tally of saplings was also increased to improve the accuracy of biomass estimates in small diameter classes. The 1982 Georgia survey was further improved for biomass purposes by adding a photo-interpreted crown closure classification to all nonforest samples to stratify the nonforest biomass sample. Inventory procedures currently being used in the North Carolina survey are essentially the same as those used in Georgia.

Weight Equations

In retrospect, the key factor in converting the Forest Survey to biomass was the availability of

weight equations for many of the important tree species in the Southeast. Thanks to the close cooperation and technical support provided by Joe Saucier's Utilization of Southern Timber Project, located at Athens, Georgia, the Forest Survey was able to obtain a set of tree weight equations suitable for broad-scale inventories. The Project scientists involved in the technology transfer efforts were Joe Saucier, Alex Clark, Doug Phillips, and Mike Taras. Without their able assistance the Forest Survey biomass work would have been delayed or possibly not attempted.

Because of the broad-scale and all-inclusive nature of biomass inventories initiated since 1978, there was still a problem of obtaining weight factors for certain minor tree species, tropicals, and lesser vegetation such as shrubs, vines, and grasses. To obtain at least a token sample of weight/volume ratios and the weight of foliage and lesser vegetation per unit of stocking, Forest Survey initiated a crash study to fill in some of the more important gaps. As improved weight equations and weight factors become available, they will replace the weaker data in the Forest Survey processing system, assuring that the very best biomass estimates possible are being used for broad-scale inventories in the five Southeastern States.

Reprocessing the Inventory Database

The remaining task of converting the Forest Survey to biomass was to reprocess the entire Southeastern inventory database and develop weight estimates for each sample tree. There were several problems that made the reprocessing of older data somewhat different from the processing of recent inventories where biomass was a planned objective. The first problem encountered was the absence of total heights for saplings in the older inventories. The only choices were to use average tree weights based on species and d.b.h. or to estimate total heights for these trees and use the tree weight equations that were available. The latter option was used because total height prediction equations were readily available for all Southeastern tree species but average weight factors by species and d.b.h. would have had to be developed for this special purpose.

Another consideration important to Forest Survey was to have the computed green weight of wood and bark in the merchantable stem (from a 1.0-foot stump to 4.0-inch top d.o.b.) consistent in terms of the weight/volume ratio with the published estimate of net cubic merchantable volume. The total aboveground weight/volume ratio should also be reasonable for each species and diameter class. An additional complication was that bole lengths were measured for all trees 5.0 inches d.b.h. and larger but total height was required for solution of the total-tree weight equations.

Total heights can be estimated with reasonable accuracy using species, d.b.h., and bole length if a large sample of trees having both bole length and total height is available for use in developing regression estimators. Forest Survey has approximately 38,000 carefully measured sample trees representing the full range of species and tree sizes found in the Southeast. This database was used to develop total height estimates as needed.

The Forest Survey volume tree database was also used to develop regression equations for predicting total aboveground cubic volume using species, d.b.h., and total height. During the reprocessing of individual tally trees, both total aboveground cubic volume and total aboveground green weight of wood and bark were computed and a total tree weight/volume ratio was calculated. This ratio, based on the entire tree, was then used to compute the green weight of wood and bark for various tree volume components.

USE OF FOREST BIOMASS INFORMATION

Forest Survey is both a user and a producer of forest biomass research results. Tree weight equations and other biomass research developed by other scientists are used to compute individual total tree weights, weights of selected tree components, various conversion rates, and other wood properties. These equations, rates, and factors are then used by Forest Survey during inventory processing to calculate the various weight components for individual inventory sample trees. All tree volume and weight values are then expanded to per-acre level and summarized by sample location. Values per tree are also expanded to population level for final inventory summarization. Individual tree and location records containing a complete array of information are then loaded into the customized Forest Information Retrieval (FIR) system database for storage and future use.

The stored biomass data are being used in a number of ways: (1) a wide variety of publications have been prepared for Forest Survey Units, States, and for the entire Southeastern region; (2) the data has been retrieved and compiled on a custom basis to meet the specific needs of various users; and (3) major studies and special projects such as the "local wood residue study" now being conducted at Clemson University are receiving data retrieved and compiled to individual specifications for designated geographic areas. For example, empirical weight yields have been developed for different forest conditions defined by forest type, site, stand origin, stocking, and stand age, using the biomass data for over 25,000 sample locations throughout the five Southeastern States.

BIOMASS PUBLICATIONS

Since we began converting Forest Survey results to biomass in 1976, a number of studies have been conducted using biomass data with results presented in terms of green weight of wood and bark. Several of these studies resulted in publications which have been distributed. Additional copies of these reports and papers are still available from the respective authors.

Bones, James T.
1981. Tree biomass - a state-of-the-art compilation. U.S.D.A. For. Serv. Gen. Tech. Rep. WO-33, 34 p.

Cost, Noel D. and Joe P. McClure.
1982. Multiresource inventories: techniques for estimating biomass on a statewide basis. U.S.D.A. For. Serv. Res. Pap. SE-228, 31 p. Southeast. For. Exp. Stn., Asheville, NC.

Cost, Noel D. and Joe P. McClure.
1982. Multiresource inventories--forest biomass in Florida. U.S.D.A. For. Serv. Res. Pap. SE-235, 24 p. Southeast. For. Exp. Stn., Asheville, NC.

Knight, Herbert A. and Joe P. McClure.
1981. Multiresource inventories--forest biomass in South Carolina. U.S.D.A. For. Serv. Res. Pap. SE-230, 27 p. Southeast. For. Exp. Stn., Asheville, NC.

McClure, Joe P.
1981. Multiresource inventories - forest biomass in South Carolina. In Proceedings of 1981 Southern Forest Biomass Workshop, Clemson University, SC.

McClure, Joe P., Joseph R. Saucier, and Robert C. Biesterfeldt.
1981. Biomass in southeastern forests. U.S.D.A. For. Serv. Res. Pap. SE-227, 38 p. Southeast. For. Exp. Stn., Asheville, NC.

McClure, Joe P., Noel D. Cost and Herbert A. Knight.
1979. Multiresource inventories--a new concept for forest survey. U.S.D.A. For. Serv. Res. Pap. SE-191, 68 p. Southeast. For. Exp. Stn., Asheville, NC.

McClure, Joe P.
1979. Multiresource inventories--A new concept for forest survey in the Southeast. In Forest Resource Inventories Workshop Proceedings. Colorado State Univ., Fort Collins, CO. p. 23-28. W. E. Frayer, ed.

BIOMASS INFORMATION -- AN INDUSTRY PROSPECTIVE[1]

Galen D. Todd[2] and Bruce E. Fox[3]

Abstract.-- The needs of the industrial forest products community for detailed biomass information have not yet been fully established. As the market value for this commodity increases, so will the requirements for data increase. It is the role of researchers and planners to have such data available as the markets begin to mature and the informational requirements become established.

INTRODUCTION

The application of biomass information by the industrial forest community is in its infancy. Since the industrial uses of biomass have not yet been widely accepted, biomass has yet to be fully recognized in practice as a product from the forest. It is, however, only a matter of time until this tremendous source of fiber and fuel will mature. The type of effort represented by meetings such as these provide the researchers and planners with the knowledge to assist in the development of informational requirements for this resource.

This paper will provide a general summary of the current and future integration of biomass information into the management of industrial forest lands.

METHODOLOGY

To better obtain this perspective, a telephone survey of representatives from a cross-section of the pulp and paper industry in the south was conducted. Although by no means a statistically sound or experimentally perfect sample, it did provide a forum for discussion to capture the current and future perspectives of the industrial community in the south.

[1]Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2]Galen D. Todd is Project Leader -- Resource Management in Timberlands, Champion International Corporation, Stamford, CT.

[3]Bruce E. Fox is Business Planning Analyst in Timberlands, Champion International Corporation, Greenville, SC.

DEFINITIONS

According to the individuals surveyed, biomass is generally defined as all above ground bark and woody material in a forest stand, excluding leaves and small branches. The general consensus is that the following definition used by the USDA-Forest Service is appropriate:

> The aboveground green weight of wood and bark in all live trees 1.0 inch d.b.h. and larger from the ground to the tip of the tree. All foliage is excluded, as is wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch at their base (McClure, Saucier, Biesterfeldt 1981).

Some companies consider a minimum age rather than diameter as more meaningful for plantations, but in general, the above definition has wide acceptance. A definition such as this is considered by all surveyed companies as both necessary and valuable in order to identify and quantify the magnitude of material produced by the forest.

However, this definition applies only to reporting, research, and planning functions. Operationally, biomass is defined strictly as residual material -- that material remaining after all traditional products have been accounted for. Biomass as a "product" has not yet been operationally accepted. Biomass is considered operationally as a slush fund of fiber -- ready to provide additional fuel or furnish or to remain as logging residue and left in the woods. Until the markets mature for biomass, the "product", an operational definition will continue to remain illusive.

INVENTORY SYSTEMS

Inventory systems are maintained by the industrial sector to provide information and data concerning their ownership at a reasonable cost. The uses of this information satisfy

operational, research, planning, and accounting needs. The general reporting functions of such systems must summarize the data in terms of units and products which meet the informational requirements of the company. Typically, the manufacturing facilities of a particular company play a significant role in determining the units of measure and product specifications reported. Given that most of the surveyed companies' processing facilities do not currently accept biomass fiber as fuel or furnish, little need exists to integrate this new "product" into their inventory systems.

Specifically, the integration of biomass information reporting into corporate inventory systems of the surveyed companies is limited to nonexistent. Most inventory systems are designed to provide reports identifying traditional products in either weight or volume units. Biomass remains uninventoried.

Only one company surveyed is actually revising sampling designs and reporting systems to include biomass information in standard summaries. The remaining companies use published conversion factors (generally volume to weight factors) applied to existing product inventory data to generate any ad hoc biomass reports.

In summary, the general consensus is that the need for statistically sound biomass information has not yet been sufficiently established to justify the cost of gathering and integrating this type of data into current inventory systems of the industrial forest community in the south.

INFORMATION REQUIREMENTS

With the recognition of biomass as a valuable product, information requirements with respect to this resource will increase. Generally, the required information will fall into four broad categories. Work in many of these following categories has already been initiated.

First, information will be needed to predict timber inventories of biomass in both weight and volume terms based on easily measured field variables. This duality in expression stems from historic practices. Land owners, including the forest industry, typically express timber resources in volume terms -- cords, board feet, cubic feet, etc. Converting facilities and power plants usually express raw material and solid fuel requirements in weight terms. Biomass inventory systems that measure and express the resource in both types of units will greatly simplify the future utilization and integration of biomass material.

Second, biomass information systems must provide a mechanism to distinguish the portion that is marketable from the total available resource. This must be a flexible system to be responsive to changing market needs. More specifically, information systems must be able to predict both total biomass and marketable proportions as a function of species mix, stand size distribution, and season of the year.

Third, because of the expected fuel use of biomass, measurements of the caloric (BTU) content (green and dry) of the resource will become important.

Fourth, information will be needed to measure the effect of biomass harvests on site productivity. When biomass harvesting intensifies, it will become vital to understand the positive and negative impacts on local site quality.

TIMING

Unfortunately, predicting when this information will be required is impossible. Biomass may gradually increase in value over time. In such circumstances, information needs will also gradually increase. On the other hand, a sudden event -- another oil embargo raising oil prices to $70 per barrel, more efficient harvesting systems or a technological breakthrough in processing, etc. -- may cause a sudden requirement for information. In either case, once the markets for biomass become established, information will be wanted immediately. Time to establish the research projects necessary to develop this information will be limited. If such information is unavailable, researchers and planners will no doubt receive criticism for their failure to accurately foresee these needs.

This fact leaves us on the horns of a dilemma: investing time and money today to develop sound biomass information may result in resentful grumblings about irrelevant research. But, failure to have this information available when required will result in equally resentful grumblings. Unfortunately, no easy pathways out of this dilemma exist.

CONCLUSIONS

The need for information about a resource depends greatly on the value (or perceived value) placed on that resource. During the early 1800's, few people were concerned about forest inventory systems of any sort in the United States. Timber was a too abundant and inexpensive commodity to spend the time and money required to inventory it. Only when a perceived scarcity of the resource developed during the closing years of that century, with a consequent increase in the value of sawtimber, were inventory systems deemed necessary. On the whole, the forest products industry in the United States is in the same position with respect to biomass. Today, as it was with sawtimber 150 years ago, no perception of a biomass scarcity exists and consequently the resource has little economic value. Therefore, little economic incentive

exists to design and implement information systems that characterize the biomass resource.

Over time, the increased value of biomass will require the modification of forest inventory systems to reflect the new market-derived product -- biomass. Until that time, researchers must continue their efforts to develop appropriate mensurational techniques to ensure the timely provision of useful information.

LITERATURE CITED

McClure, Joe P., Joseph R. Saucier, and R. C. Biesterfeldt 1981. Biomass in Southeastern Forests. USDA Forest Service Research Paper: SE-227, Southeast Forest Experiment Station, Asheville, NC. Page 2.

GEORGIA'S EXPERIENCE WITH THE BIOMASS TIMBER CRUISE PROGRAM[1/]

Lynn B. Hooven[2/]

Abstract.--This paper summarizes the introduction and use of the Total Biomass Cruise Program by the Georgia Forestry Commission. Some of the topics discussed include: the adoption of the program by the Commission; training of personnel; introduction of the system to the landowners; and the usage of the system throughout the State.

In the State of Georgia, the increasing demand for wood chips, as an alternative fuel source, has greatly increased the need for forest biomass information. The introduction of the Total Biomass Cruise Program (TBCP) provided a timely solution in helping to meet this need (Clark and Field 1981). The TBCP calculates biomass estimates and requires little more than conventional plotless prism cruise data for input. The Georgia Forestry Commission (GFC) was able to readily adopt the program since prism cruising was already widely used by Commission foresters. In order for the Commission to make use of TBCP in their landowner assistance program, the only additional cruise data required were total tree height and a tally of two- and four-inch stems.

In order to maximize the benefits of this new system and encourage its use, the GFC conducted training of all personnel. Training sessions were held throughout all 12 districts within our State for both professional foresters and secretaries. Foresters received information that polished their skills in three areas: (1) prism cruising to ensure the accuracy of field data collected, (2) computation of collected data, and (3) the proper sequencing of data into the computer terminal. Secretaries were trained in compiling data and entering it into the computer terminal. This training gave the GFC personnel confidence in the usage of this system. To gain even more confidence in this system, some foresters compared the output data from the computer printout to previously obtained figures from conventional cruises.

Another aspect of the introduction of a new system is the "selling" of this system to users. Ray Shirley, former director of GFC, familarized state representatives with this system in 1981 and pledged that Commission foresters would run a biomass cruise for each of their farms upon request.

Since 1981, 22 demonstrations of whole tree chipping operations and total biomass cruising programs have been demonstrated to landowners statewide from Rome to Waycross. In response to this exposure, there were requests for this type of cruise data. Since a number of these requests came from real estate speculators and landowners only interested in inventory figures, it was necessary for the GFC to follow the guidelines for timber cruising as outlined below:[3/]

Procedure: Total volume estimation will be advisable and permissible under certain conditions and circumstances for small ownerships providing total work time does not exceed five working days per year per landowner and will meet one of the following criteria.

1. Understocked or poorly stocked stands that should be clearcut and regenerated.
2. Removal of worked out naval stores timber.
3. When timber stand has stagnated with no future growth potential apparent.
4. Timber stands with 400 or more well-spaced desirable seedlings per acre with overstory of stagnated, mature and overmature trees.

Initially, this system was used six or seven times per week. Part of this usage was due to numerous requests made by state representatives. During the past six months, usage of TBCP has averaged twice weekly. The primary requests have been from a logging radius around Rome and Macon, which are the major centers for wood chip operations.

There are approximately 179,000 non-industrial, private landowners in the State of Georgia. They own 65 percent of the state's 24,000,000 acres of forest land. These landowners need to more fully appreciate their renewable natural resources and additional understanding of forest biomass would help accomplish this goal.

[1/] Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2/] Author is Associate Chief, Forest Management, Georgia Forestry Commission, Macon, GA.

[3/] From the Policy and Procedure Manual, Georgia Forestry Commission, 1979.

Our role in state forestry programs is to anticipate the needs and problems to be faced in the future. The TBCP will help enable the non-industrial, private landowner to meet these needs as they arise with better knowledge about the value of his forest resource.

LITERATURE CITED

Clark, Alexander III, and Richard C. Field. 1981. Total Biomass Cruise Program - Georgia User's Manual. Unpublished document on file with Ga. For. Com. available upon request, 40 p.

Clark, Alexander III, and Richard C. Field. 1981. TBCP...A computer program that estimates: total tree chips, saw logs, pulpwood, firewood. Ga. For. Res. Pap. No. 21, Ga. For. Com., Macon, GA, 7 p.

Phillips, Douglas R., and Joseph R. Saucier. 1981. Cruising procedures for estimating total stand biomass. Ga. For. Res. Pap. No. 5, Ga. For. Com., Macon, GA, 12 p.

SESSION 3

UTILIZATION OF FOREST BIOMASS

Moderator: Alexander Clark, III

SOURCES OF UNUTILIZED FOREST BIOMASS AND IMPLICATIONS TO FOREST MANAGEMENT

Douglas R. Phillips

Abstract.--Recent large increases in the cost of fossil fuels and the development of the total-tree chipper have made it profitable to harvest would-be logging residues in many stands. Stands that are scheduled to be cut should be evaluated for total-tree chipping to determine the quantity and quality of additional biomass that could be removed and potential detrimental effects on site quality that would be realized from the additional loss of nutrients and organic matter.

Many stands that are in need of silvicultural treatment can now be treated by using the receipts from total-tree chipping to offset the cost of the operation. To determine which stands can be entered, the above criteria (i.e., quantity and quality of available biomass and possible nutrient depletion) should be considered along with the improved potential of the stand over the next rotation.

INTRODUCTION

proull et al. (1957) introduced the
l-tree utilization 25 years ago, in-
y of woody biomass has steadily im-
ughout the 1960's main stem utili-
sed, but the opportunity for signif-
s appeared in the early 1970's with
f the total-tree chipper. This new
h chews up a tree from butt to tip
f seconds, was first directed at
s for the paper industry. But
re not readily accepted and the
pper saw only limited use. How-
the Arab oil embargo caused fossil
skyrocket and suddenly forest
in demand for fuel.

chippers in use in the United
d dramatically from 110 in 1972
94 through 1979 (Plummer 1981).
the opportunities this new
and began to quantify and pro-
forest residues (Zobel 1977;
0; Phillips 1979). Today, total-
re quite common in the South and
pected to increase.

onal biomass that can be retrieved
hipping all above-ground tree
d the interest of utilization ex-
dditional loss of nutrients has
y those who evaluate site qual-

The benefits of removing all woody biomass from a site are: (1) the salvage of millions of tons of forest biomass for fuel and fiber, (2) the reduction in the cost of silvicultural treatments, and (3) improved site preparation for natural regeneration or planting. The liabilities are: (1) loss of nutrients, and (2) loss of organic matter. This paper analyzes sources of unutilized forest biomass in the southeastern United States and identifies the ones that provide the best opportunity for utilization with the least amount of damage to the site.

SOURCES OF UNUTILIZED FOREST BIOMASS

Available sources of forest biomass generally fall into two categories: (1) "living residues" and logging slash left on the site following harvest, and (2) poor quality stands that need biomass removed as part of a silvicultural treatment. Within each category, differences between pine and hardwood stands can be important, so as each source is discussed, these differences are highlighted.

Residual Biomass on Harvested Stands

Traditionally, large amounts of biomass have been left during harvests in most stand types in the Southeast. These residuals include both living trees and logging (or felled) residues.

Living Residues

Living residues are small trees, culls, or unwanted species that are alive and standing after harvest (Welch 1980). The amount of living residues left on the site depends largely on the type of stand. In pine plantations, only 6.1 of the 36.4 tons of biomass per acre are left following harvest (Table 1). The small average initial biomass is a reflection of the short rotations and younger trees associated with plantation management. The amount of residual biomass following harvest is small in plantations because the stand has been managed to produce a limited number of stems of the desired size.

In natural pine stands, 16.1 of the average 71.2 tons of biomass per acre are left following harvest. Three-fifths of this material is softwood and two-fifths is hardwood. The softwood component is primarily trees too small to harvest, and the hardwood component is small trees plus some larger trees that are culls or unwanted species.

Oak-pine stands contain an average of 65.9 tons of biomass per acre, and when they are harvested some 31.0 tons of living residues are left on the site. Thus, almost half of stand biomass is left. Since hardwood residuals outnumber softwoods 3 to 1, species composition is changed in favor of hardwoods.

Upland hardwood stands contain more biomass (76.8 tons per acre) than oak-pine stands and have slightly higher living residues (33.8 tons per acre). The vast majority of residuals in this stand type are hardwood.

Bottomland hardwood stands have the highest initial biomass (99.1 tons per acre) and the highest residual biomass following harvest (50.7 tons per acre) (Table 1). Two factors contribute to the unusually large quantities of living residues on these sites. First, many bottomland stands are inaccessible and difficult to log due to frequent flooding or high water tables, so many residual cull trees have been left on the site. Second, markets for hardwood pulp and fuelwood are often lacking.

Logging Slash

Logging residues are made up of tree crowns and small stems that have been cut or destroyed during logging. The amount of logging residue on a given site varies greatly depending on the type and number of trees harvested, and on the level of utilization. Information by stand type is not available, but Knight and McClure (1981) estimate from data presented by Welch (1978) that logging residues average 18 tons per acre across all stand types in the Southeast.

Integrating Silviculture with Utilization

In conventional logging operations in the South, only the main stems of pulpwood- and sawtimber-sized trees of commercial species of acceptable quality are removed. Logging residues left in the woods rot away and, while the utilization expert might consider this an unnecessary waste, the ecologist or silviculturist might argue in favor of leaving these residuals to return nutrients and organic matter to the site. Not so for living residues. They not only represent unutilized biomass; they inhibit the development of a new stand. Residual trees take up valuable growing space, and they are seldom of the right species. Even if the species are desirable, they seldom respond to release because the trees have been overtopped for many years. The majority of understocked, poor quality stands we have today resulted from this harvesting method. The need, therefore, is to consider silvicultural effects when utilization decisions are made.

All too often we examine the forest in only one context (i.e., its product potential or its management potential). A stand is unlikely to be cut if a utilization expert says stocking is insufficient for a profitable harvest. A silviculturist's contention that cutting is needed to make room for a more productive stand may be ignored if the entire cost of cutting cannot be

Table 1.--Total Stand Biomass and Residual Biomass Following Harvest by Stand Type in the Southeast.

Stand type	Total stand biomass	Standing biomass left on site following harvest[1/]		
		Softwood	Hardwood	Total
	Green tons/acre			
Pine plantation	36.4	4.2	1.9	6.1
Natural pine	71.2	9.4	6.7	16.1
Oak-pine	65.9	7.8	23.2	31.0
Upland hardwoods	76.8	3.0	30.8	33.8
Bottomland hardwoods	99.1	5.1	45.6	50.7

1/ All live trees on the site following harvest. Welch (1980) called this material "living residues."

offset by income from the present sale. If the two specialists worked together, they could probably identify many stands that could be treated economically by using receipts from the sale of firewood and chips to help offset treatment costs.

Biomass Yields Through Treatment Opportunities

To determine which stands afford the best opportunities for these improvement harvests, I have examined data from the most recent forest inventories in the five southeastern States from Virginia to Florida. When Forest Inventory and Analysis field crews visit forest stands, they classify them according to treatment needs or treatment opportunities. They examine species composition, stocking, stand age, etc. and determine if there is a need for silvicultural treatment and, if so, what the need is. In the Southeast, 33.3 of the 87.4 million acres of commercial forest land are classified as needing some treatment. Just over 44.4 million acres are classified as needing no treatment and the remaining 9.7 million acres are adverse sites (Table 2). Adverse sites are upland sites with slopes in excess of 40 percent and bottomland sites that have year-round standing water.

By far the treatment most often prescribed is stand regeneration. Stands in this condition do not have sufficient stocking of commercial species to justify carrying the stand to maturity. The 15.2 million acres in this condition would be much improved if they were cut and regenerated to even-aged stands of pines or hardwoods (Table 2). Upland hardwood stands (5.9 million acres) are the ones most often given this classification, but other stand types also need regeneration--natural pine (3.8 million acres), oak-pine (2.2 million acres), and bottomland hardwoods (3.0 million acres).

Other treatments in which the entire stand would be cut are salvage (0.7 million acres), harvest (4.7 million acres), and conversion (3.0 million acres) (Table 2). Salvage cuts are required when stands have been severely damaged by ice, insects, disease, or other agents. Harvest cuts are recommended for stands that are mature or overmature in which growth has slowed substantially. A stand is recommended for conversion if it is determined that a different species or species combination would be better suited for the site.

Some stands are not ready for final harvest but would benefit from some biomass removal. In the Southeast, 5.6 million acres need timber stand improvement work, and an additional 4.1 million acres need thinning.

The 33.3 million acres just described as needing silvicultural treatment can provide large amounts of biomass if and when they are treated. Average stand yields, in tons per acre, by treatment opportunity class and broad management class, are given in Table 3. Stands requiring salvage cuts contain an average of 80.4 tons of biomass per acre; those requiring harvest cuts, 130.9 tons per acre. Biomass in stands ready for harvest is large because the stands are fully stocked with mature trees.

The stands that need to be regenerated contain, on the average, only 32.0 tons of biomass per acre. The hardwood stands in this category contain from 33 to 43 tons per acre, but even the higher tonnage often cannot justify total-tree chipping if silvicultural benefits are ignored. One must consider the long-range benefit of converting 15 plus million acres from marginally productive to very productive areas and use the receipts from the chipping operation to offset treatment costs.

Table 2.--Area of commercial forest land by broad management class and treatment opportunity class in the Southeast (VA, NC, SC, GA, FL).[1/]

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwoods	Bottomland hardwoods
	(Thousand acres)					
Salvage	706	148	356	65	59	78
Harvest	4,701	10	1,152	517	1,601	1,421
Regeneration	15,217	305	3,817	2,164	5,924	3,007
Conversion	2,993	29	432	531	1,718	283
Timber stand improvement	5,643	204	1,448	1,164	1,919	908
Thinning	4,055	1,116	2,359	143	148	289
None	44,442	8,076	14,975	5,262	11,314	4,815
Adverse sites	9,661	40	653	672	5,571	2,725
All classes	87,418	9,929	25,192	10,518	28,253	13,526

[1/] Data provided by Forest Inventory and Analysis Work Unit, Southeastern Forest Experiment Station, Asheville, NC 28804.

Table 3.--Average green weight of forest biomass per acre by broad management class and treatment opportunity class on commercial forest land in the Southeast (VA, NC, SC, GA, FL).[1]

Treatment opportunity class	All management classes	Broad management class				
		Pine plantation	Natural pine	Oak-pine	Upland hardwoods	Bottomland hardwoods
	(Tons/acre)					
Salvage	80.4	70.7	88.2	79.1	83.0	106.9
Harvest	130.9	114.9	117.1	122.8	125.3	153.0
Regeneration	32.0	11.4	18.7	33.3	35.6	43.1
Conversion	50.6	34.6	49.9	51.2	50.2	54.1
Timber stand improvement[2]	40.4	23.7	34.7	40.0	43.2	47.5
Thinning[2]	16.6	8.4	16.6	21.0	22.3	42.9
None[2]	18.4	3.4	15.6	22.0	25.1	32.6
Adverse sites	97.9	82.1	77.7	74.0	93.8	117.4

[1]Data provided by Forest Inventory and Analysis Work Unit, Southeastern Forest Experiment Station, Asheville, NC 28804.

[2]Biomass values are for only those trees that are competing with, or are incidental to, crop trees. Biomass values for all trees in the stand would be considerably higher.

Timber stand improvement cuts and thinnings can also be valuable sources of biomass. Stands that need an improvement cut contain an average of 40.4 tons of biomass per acre that could be removed, while stands that need thinning contain an average of 16.6 tons per acre that could be taken out. These figures represent the minimum biomass that should be removed, but in many cases much more could be taken out without interfering with the stand. Again, these cuts should be evaluated on the basis of stand improvement as well as dollar returns from the sale of chips taken out during the cut.

CONCLUSIONS

Two primary sources of unused biomass have been discussed: (1) living and logging residues following harvest, and (2) biomass that could be removed during the silvicultural treatment of existing stands. Salvage of harvesting residues is better accomplished before or during the harvest of larger sawtimber trees. Preharvest removal of understory and cull trees allows the sawtimber trees to be cut in a follow-up operation at less cost than if the understory trees were still on the site (Cochran 1983). The during-harvest removal of small trees and culls is usually done by skidding whole trees to a landing where sawlogs are removed and the remaining portion of the tree is chipped. Both systems usually leave the site clean and ready to be planted or naturally regenerated to an even-aged stand.

The higher the potential residue volume on a site, the easier it is to justify recovery. For example, in pine plantations where only an average of 6.1 tons of biomass per acre are left following conventional harvesting, there is little incentive to total-tree chip. But on bottomland sites where an average of 50 tons per acre of living biomass remains on the site, or on upland hardwood sites where almost 34 tons per acre remain, total-tree harvesting is much easier to justify. Not only is the quantity of available biomass higher, but the quality is better because more woody material is included. Also, if these living residues are not removed, a poor quality stand will probably develop or the material will have to be destroyed at considerable costs during site preparation for the new stand.

The second source of available biomass (material removed during stand treatment) is there largely because of past harvesting practices. Poor-quality stands that developed after partial high grading cuts now need regeneration, conversion, or timber stand improvement. Productive stands also can be sources during harvest cuts and thinnings. As with the first source of available biomass, the higher the quantity and quality available, the easier it is to justify its retrieval. But a second factor is extremely important here. Through the removal of this biomass, how much can the stand be improved? When both factors are considered, the 15.2 million acres that need to be regenerated look much more attractive. These stands do not contain tremendous amounts of biomass (32 tons per acre, on the average), but we must ask ourselves how long we are willing to carry 15.2 million acres that are so poorly stocked they are classified as needing complete regeneration.

If we are to meet projected demands for wood products, we must do a better job of salvaging harvesting residues and we should begin to treat stands that are in such poor condition that their

productivity is minimal. Producing good quality trees is a long-term business. We must start now to grow the trees we know we will need 20 to 30 years from now.

LITERATURE CITED

Cochran, C.W.
1983. Total utilization of the South's small trees--multipass harvesting. Speech presented at Forest Products Research Society Meeting, April 18-20, 1983, Biloxi, MS.

Knight, H.A. and J.P. McClure.
1981. Multiresource inventories - forest biomass in South Carolina. Res. Pap. SE-230. U.S. Dept. of Agric., For. Serv., Southeast. For. Exp. Stn., Asheville, NC. 27 pp.

Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

Author is Project Leader, USDA Forest Service, Southeastern Forest Experiment Station, Department of Forestry, Clemson University, Clemson, South Carolina.

Phillips, D.R.
1979. Forest residue: A significant source of energy. Southern Lumberman 239(2967):101-103.

Plummer, G.M.
1981. The present state of whole tree harvesting. TAPPI 64(4):71.

Sproull, R.C., R. B. Parker, and W.L. Belvin.
1957. Whole tree harvesting. For. Prod. J. 7:131-134.

Welch, R.L.
1978. Predicting logging residues for the Southeast. Res. Note SE-263. U.S. Dept. of Agric., For. Serv., Southeast. For. Exp. Stn., Asheville, NC. 4 pp.

Welch, R.L.
1980. Living residues in the South Atlantic States. For. Prod. J. 30(6):37-39.

Zobel, B.J.
1977. Will timber resources of the southern United States meet the demands? TAPPI 60(6): 51-53.

SYSTEMS AND PROCEDURES FOR INTEGRATED RECOVERY OF FOREST BIOMASS [1/]

T.A. Walbridge, Jr., and

W.B. Stuart [2/]

Whether recovery of forest biomass will become a common procedure depends on how acceptable biomass is for fuel and fiber, what the demand is for it, how stable is its supply, and how economic it is when it comes to energy. Manufacturers appear interested in continuing to develop machines and systems that recover biomass resulting from silvicultural treatments, final harvests, and site preparation.

INTRODUCTION

In 1979, the energy-intensive pulp and paper industry generated an estimated 54% of the energy it used from wood fuels and spent pulping liquors (American Paper Institute 1980). Likewise, solid wood products produced 70% of its energy needs from purchased and self-generated wood fuels (National Forest Products Association, 1980). Besides the economic benefits derived from the use of these low-cost fuels, the industry has increased boiler combustion of mill wastes in response to stricter air quality and landfill regulations (Reisinger, 1981).

More and more nonforest-based industries are recognizing the benefits of converting to wood for fuel, while almost complete energy self-sufficiency is the avowed goal of the pulp and paper industry. All these factors point to a dramatic increase in competition for existing supplies of wood fuels (Reisinger, 1981). A 1979 American Pulpwood Association survey projected that usage of forest residues will increase rapidly from the current 1% to an estimated 6% of total energy wood consumed by Southern pulp and paper companies by 1983 (Kluender, 1979). Forest biomass is also used as fiber for the paper and fiber board industries. Chip beneficiation may expand this use. It also appears to have potential as a feedstock for chemical production.

Fortunately, most wood-based industries have the infrastructure to obtain and handle these residues. Our purpose is to present both the state of the art of systems and the procedures for integrated recovery of forest biomass and future systems being tested and envisioned. These systems may be used during silvicultural treatments, final harvests, or site preparation.

SILVICULTURAL TREATMENTS

We define silvicultural treatments as operations that improve the health and quality of the stand. These operations usually include cleanings, thinnings, and timber stand improvements. Cleanings and thinnings are excellent potential sources of biomass.

Cleanings

Cleanings are usually made to reduce stocking and are carried out at a very young age. In Scandinavia, motor-manual systems are commonly used. Called "laying to waste," cleanings in New Zealand and Australia are carried out with machetes. A variety of mechanical methods have been used to reduce stocking and bring about a plantationlike configuration. Some of the more common methods are bulldozers, V-blades, chain-flail, and rotary cutters. In the past, none of these methods has been used to recover biomass. Their major purpose was to cut, or otherwise destroy, unwanted stems and undesirable species.

2/Professor, VPI & SU, Blacksburg, VA. Assistant Professor, VPI & SU Blacksburg, VA.

The anticipated demand for forest biomass for fuel suggests that one source might come from the recovery of cleanings. At present at least two machines may have application. Both the Georgia Pacific Biomass Harvester and the Koch-Nicholson Mobile Chipper are swath fellers that chip material immediately after felling.

The Georgia Pacific machine uses a cutter head consisting of two counter-rotating wheels with cutting teeth for felling, and a 1.22-m, 2-knife, slant-disk Treland chipper. These units are mounted on the front section of the machine. The rear section of the tracked, articulated base carries the power unit and a 6.8-m^3 side-dumping chip hopper. This machine was developed specifically to capture the biomass generated when swaths were cut through overstocked, naturally regenerated or direct-seeded stands. The swath is about 2 m wide, the "leave" strips are 3/4 to 1 m wide, and, by extensive maneuvering, all commercial quality trees are left. Production is from 5 to 8 metric tons/hr. Production from cleanings in plantation stands is about 8-11 metric tons/hr.

The Koch-Nicholson Mobile Chipper uses a felling bar and a drum chipper to recover small trees, brush, and logging debris. It does not appear to be as maneuverable as the Georgia Pacific machine, but as a swath feller it might be used for corridor cleanings.

Both of these mobile chippers require chip forwarders to complete the recovery of the biomass chips. Obvious drawbacks are high initial capital investment, high horsepower requirement, large size, and weight. With such drawbacks, these machines are limited to nearly flat and rock-free terrain.

Schoonover has developed a low-ground pressure tracked machine which mounts a swinging chopper for land clearing. The manufacturer plans to offer three models: the Shar 10, Shar 20, and Shar 30. The Shar 10 and 20 mount a single chopping head and are suited to clearing brush and cleaning stands. Neither model recovers the resulting biomass. Model 30 will mount two counter-rotating chopper heads and an on-board chipper. Chips will be blown to a van following the harvester. Model 30, like the Shar 10 and 20, will be hydrostatically driven. Production is expected to be 1-2 ha/hr.

Thinnings

If cleanings are considered to include pre-commercial thinning to reduce stocking or competition, then thinnings can be considered as having commercial value. The major purpose of thinnings is to put growth on fewer trees and improve their quality.

Methods of thinning range from highly labor-intensive systems to highly mechanized systems. Labor-intensive systems offer the greatest opportunity for selective thinning, while highly mechanized systems usually require a "mechanical" approach that includes row thinning or herringbone patterns that reduce machine maneuvering (Lane, 1981).

Thinning systems normally produce short wood at the stump or tree-length material at the deck. These systems usually leave tops and limbs in the woods. In order to recover biomass, thinning systems must be altered to skid or forward whole trees or tree segments. Two labor-intensive systems that can be used to recover biomass from thinnings are the Nordfor system and the use of small winches mounted on two- and four-wheel-drive farm tractors.

The Nordfor system, which was developed in Sweden, is a method that uses highly skilled sawyers to select, fell, and place thinned trees in such a way that they can be removed by a special cable yarder. The yarder, known as the Tilt-Winch, is mounted on the rear section of a skidder or forwarder and uses a specially designed capstan winch to pull four or five full trees per drag in a fiber-glass nose cone or sled from the woods to the landing. Yarding is usually limited to about 125 m, and a light haulback line allows rapid return of the rigging and sled to the woods. Wood is normally stockpiled along a road or strip road for chipping.

Skidding of full-tree thinnings with winches mounted on farm tractors is a labor-intensive system that requires cooperation between the sawyer and the tractor operator. The Farmi from Finland and the Norse from Norway are two makes being imported. Both are easily mounted to the three-point hitch of the tractor and are power take off driven. Recent experimentation with a small Farmi winch mounted on a 22-kW Kubota 4-wheel-drive farm tractor in Virginia and North Carolina demonstrated that labor-intensive methods using small equipment require careful planning and supervision if they are to be competitive with other thinning methods (Pennanen, 1981). This study indicates that instituting full-tree skidding into the system would require drastic changes in job layout and would result in a major reduction of machine capacity.

Highly mechanized thinning systems usually use small rubber-tired or tracked feller-bunchers, and full-tree inwoods transport is carried out by grapple-skidders. A common procedure is to remove an entire row of the plantation for access and thin between rows in a mechanical fashion. Between-row thinning is often in a herringbone pattern which allows the use of

accumulating shears with a minimum of side-to side maneuvering. The "herringbones" are usually at 30° to the clearcut row to facilitate skidding.

The Scandinavians have developed a forwarder-mounted, long-reach, sliding boom to accumulate full trees along the strip road. Trees are felled at right angles to the strip road and parallel to each other. The forwarder with the sliding boom reaches out about 10 or 15 m to grasp trees and move their butts into the strip road. A second machine grasps, bucks, and loads this accumulation of tree segments onto its forwarder chassis. This method of handling thinnings for biomass has been named "tree portioning" or "tree sectioning."

The trees are segmented in "tree portioning" using a hydraulic chain saw incorporated into the grapple of the knuckle boom loader. The operator grasps the trees at a desired point, lifts them clear of the ground, activates the saw, and loads the material remaining in his grapple. The tree sections are transported to roadside where they are loaded onto trucks or trailers equipped with compaction equipment. The material is compressed as much as possible to provide an economical load for hauling. Drum debarkers are being used for the initial processing of the tree sections. The drum action limbs, debarks, and separates the material into conventional product components and fuel. The key question in the handling of tree portions and the secret to success is how the wood can be effectively compacted for secondary transportation or hauling (Skogsarbeten, 1980-81).

FINAL HARVESTS

The term "final harvest" is used here to denote the clearcutting of forest stands for forest products including forest biomass for fuel and fiber. In order to recover biomass during clearcutting, the system must incorporate full-tree skidding, full-tree forwarding, forwarding of tree portions, or full-tree yarding. Recovery of biomass after skidding, forwarding, or yarding of limbed material is not considered the best way to recover biomass.

Several studies have addressed the question of how to best handle the accumulation of residues. The simplest method is probably to skid, forward, or yard the trees while the biomass is still attached to them - in otherwords, full-tree transport to the processor. In such "hot" operations, large and expensive chippers are often not used well enough and resulting costs are prohibitive. Skidding to intermediate landings and leaving the residues in "cold decks," or temporary storage, is one method of breaking the interdependency between skidding and processing, which can result in major improvements in chipper productivity and cost reduction (Kluender, 1982).

Baling as a way of capturing logging residues is one idea. Its major advantages are: its capital requirements are relatively low, it is a simple and easily maintained machine, it fits the independent contractor system, it produces a form of material easily stored, and it can be handled by conventional materials-handling equipment. Simulations of baler performance on a variety of stands and cutting regimes indicate that baling is economical when it does not interfere with the flow of roundwood products and is done at the same time (Porter, 1979). Crushing prior to and in preparation for baling has been suggested as a means of producing a more uniform bale.

SITE PREPARATION

Recovery systems to process, accumulate, and deliver logging residues during site preparation must be capable of traversing the area to be treated. Both the Georgia Pacific Biomass Harvester and the Koch-Nicholson Mobile Chipper are designed to perform these tasks. Both are limited by rough terrain and rocky ground. The Shar 30, if it does what its designer intends it to do, will be able to negotiate 50% slopes and avoid rocky areas. With these capabilities, it should have a much wider application than the Georgia Pacific and Koch machines.

In areas of heavy logging debris, common practice has been to shear and pile all remaining cull trees and logging residue. This material is usually windrowed for later burning. Major problems are the disturbance of topsoil between windrows, soil in the windrows, and loss of topsoil from erosion. In many cases burning of these windrows has been relatively unsuccessful, and valuable land is occupied by old windrows that pose formidable barriers to planting. A potential solution to this problem, which may also provide a means of recovering biomass after conventional harvesting, is the use of the "Force Biomaster." This device is an attachment to front-end loaders which appears to be a combination of root rake and a log loader. It has an advertised clearing productivity of 1-1.5 ha/hr. A major feature of its performance is that hydraulically operated raking teeth trip on impact with stumps and rocks and reset immediately. Since these teeth do not push and dig stones and dirt, windrows and slash piles are much cleaner. In addition, the grappling arms and loader mounting allow it to crush, load, and carry slash. It is this feature that appears to offer the opportunity to carry logging residues to tract-mobile chippers or balers.

Another device for gathering logging residues is the Rec-U-For, being developed

in Canada. Like the Force Biomaster, it is an attachment to conventional carriers. The pickup head is formed of heavy steel teeth mounted on a rotating axle. As the carrier moves forward, the teeth comb the ground surface, picking up limbs and tops and carrying them to the bed of the unit. The slash is cut or broken into short length or billets as the pickup teeth rotate through a bar grating on the bed. The billets are then carried to a hopper for collection and transfer.

SUMMARY AND CONCLUSIONS

Systems and technology to recovery forest biomass from silvicultural treatments, final harvest, and site preparation are presently in place. It appears that manufacturers are sufficiently interested in these activities to continue to develop machines to capture and process biomass. The question that remains is, will it happen? As usual, the only thoughtful answer is, it depends.

First of all, it depends on whether forest biomass in the long run will be acceptable for fuel, fiber, and feedstocks. Certainly, continued and expanded use will be a function of its cost relative to alternatives. Secondly, it depends on whether sufficient markets will develop to allow the support of systems used for biomass recovery. Finally, the systems must produce the biomass at an acceptable cost, relative to alternatives, or be justified as an investment in the future value of the forest.

LITERATURE CITED

Kluender, R.A.
1979. Mill energy consumption survey, American Pulpwood Association Rept. No. 79-A-10.

Kluender, R.A., and W.B. Stuart.
1982. Operational and Economic Consideration for Whole Tree Chip Contractors, Maine Wood Energy Conference, Orono, Maine, 11pp.

Lane, R.A., Jr.
1981. "An Evaluation of Operational Harvesting Techniques and Systems Applicable to the Commercial Thinning of Southern Pine Plantations," Masters thesis, VPI and SU.

Pennanen, O.H.
1981. "The Potential of Farm Tractors with Winches for Thinning Loblolly Pine Plantations," Masters thesis, VPI and SU.

Porter, C.D.
1979. "The Economic Feasibility of Modifying Six Conventional Harvesting Systems to Recover Logging Residues for Fuel and Fiber,: Masters thesis, VPI and SU.

Reisinger, T.W.
1981. "An Evaluation of In-Plant Handling Systems for Utilization of Wood Residues as Fuel in the South," M.S. Thesis, VPI and SU.

American Paper Institute.
1980. U.S. Pulp, Paper and Paperboard Industry 1979 Estimated Fuel and Energy Use by Region, 2 pp.

National Forest Products Association.
1980. Industrial Energy Program 25 Report, 6 pp.

1980-81 Annual Report from Skogsarbeten.
1980-81. Logging Research Foundation, Stockholm, Sweden, 8 pp.

FOREST INDUSTRY CONVERSION AND PROCESSING OF BIOMASS[1]

Aga M. Razvi[2]

Abstract.--Biomass has been used for production of pulp and paper and the generation of steam since the early seventies. Only in the past few years have mills begun to realize its economic impact. The operations from forest to paper are being considered as a single system, and the impact of different types of chips on these operations are discussed. Finally, steps that need to be taken for the enhancement and assurance of the raw material quality are presented.

INTRODUCTION

Interest in the utilization of biomass for producing pulp and paper began in the early seventies. At that time our industry was beginning to feel a fiber crunch (Karter 1974). Later, the soaring costs of fuel oil and natural gas gave the industry a further impetus to explore and utilize biomass for generation of process steam and electrical power.

Recognizing this, several companies embarked on programs to effectively utilize the biomass that was traditionally left behind after a harvesting operation. It was obvious that the yield per acre would be boosted instantaneously if the whole tree was chipped and used for pulping. This was certainly an incentive to the foresters. It was also an incentive to wood procurement organizations especially because the cost per green ton would be less if no separation of the parts of the tree was to be made during chipping.

It was easy to quantify this data and thus justify the utilization of this kind of fiber for the production of pulp and paper. In the meantime, several government departments, educational institutions and other trade associations launched programs related to volume studies of such available biomass and assessing its value.

By the mid-seventies, the program was being actively pursued by several companies, who had now gained experience and were beginning to realize the detrimental effects of utilizing this material especially in the pulping process. At this point equipment manufacturers began to market equipment that would be capable of separating some of the undesirables that were believed to be the key to the negative impact on operations. Consideration had also begun to improve harvesting techniques so that undesirable parts of the tree could go as fuel and the desirable portion for pulping.

It was only in the late seventies that some seriousness was given to evaluate the overall economic impact on the entire operation, beginning from harvesting and site preparation aspects all the way to the end product. Data is still weak in certain service areas, but with reasonable assumptions, it is possible to evaluate the economic impact on an operation and logically determine the kind of material that is best suited for a mill's product.

---

[1]Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2]Manager of Design,
Corporate Engineering Department
Westvaco Corporation
New York, New York 10171

THE OVERALL SYSTEM

The overall system commences at the forest and terminates at the paper machine. Each area in the system is treated separately, and the impact of utilizing biomass is discussed. Relative indexes have been developed using clean chips as the base, and these are shown in Table 1. These indexes can be effectively used if the absolute usage data for a specific location is available.

Table 1.--Relative Indexes per Unit Production. Clean Chips = 1.0.

Item	Softwood		Hardwood	
	WSC	WTC	WSC	WTC
Fiber at Mill Gate:	1.08	1.17	1.09	1.21
Cooking Chemicals:	1.14	1.27	1.09	1.24
Evaporator Steam Demand:	1.23	1.42	1.16	1.34
Black Liquor Solids:	1.18	1.34	1.13	1.28

WSC: Whole Stem Chips
WTC: Whole Tree Chips

Timberlands Operation

If the timberlands operation is looked upon as a system in itself, there appears to be a tremendous advantage in utilizing the entire biomass. In comparison with normal cruises for pulpwood and sawtimber harvesting, overruns of 20% have been obtained in softwood whole tree chips and 40-100% in hardwood whole tree chips. About 10% gains have been recorded on whole stem chips for both species. This itself clearly gives increased yields per acre in like percentages, thereby indicating that less land can be held and managed for a pre-established self-sufficiency requirement, resulting in both capital as well as operating cost savings. Savings also occur in site preparation costs and utilization of land occupied by windrows. Less acres have to be harvested for a given cutting budget, which could result in savings in harvesting costs as well.

Wood Procurement Operation

The procurement of fiber for pulping or fuel is obtained in different forms from various sources and by various modes of transportation. Once the material reaches the mill gate, the mill operations take over.

Over the years shortwood suppliers have basically vanished as the trend has been towards supplying longwood. Depending on the mill's operation, the longwood is either bucked at a collection yard or slashed to shortwood at the mill site and only then debarked conventionally in drums before being chipped.

The trend today is to minimize the elaborate handling, debarking and chipping of roundwood at a central mill woodyard and to move towards supplying the fiber in the form of chips ready to be fed to the digesters. This has resulted in satellite chip mills that replace collection yards and provide a reliable and continuous supply of raw material with minimal inventory of fiber at the mills. The mill woodyard, in turn, is now concentrating on inventory management, efficient handling and quality control of the fiber.

Furthermore, the chipping of whole trees and whole stems in the woods is accomplished through the wood procurement department and, in most cases, the chips are transported directly to the mill. Since contractors are paid by the ton of chips produced, they chip more tons of whole tree chips for a given area. If limbs are not separated and no grading of the stem has to be done, then fiber costs can be attractive.

Woodyard

The woodyard operation should essentially provide quality material to the pulp mill. In order to assure this, quality control should be exercised by testing the material received according to pre-set specifications and then accepting or rejecting the material. The quality of chips produced in the mill woodyard should also be checked and controlled.

Inventory management is another important aspect that must be carefully planned and implemented. Foliage, bark and fines cause pile decay resulting in loss of yields. It is important that separate piles be used for storing clean chips, whole stem chips or whole tree chips and that they be blended in as uniformly as possible through properly controlled reclaimers.

Chip classification is an essential part of the operation so that the oversize and fines are separated and a uniform chip is delivered to the digesters. All rejects from chip screens and classifiers should be sent to a power boiler as fuel.

Pulp Mill

Digester output is a good measure of wood furnish quality and bears a finite relationship to the amount of wood required to sustain a required production level. It also effects the long-term planning aspects of forest and land management by setting pre-established self-sufficiency goals.

Based on the production of the same quantity of oven dry tons of pulp, Table 1 shows the relative indexes for wood required at the mill gate. Clean sawmill chips specified at no more than 2% bark content have been used as the base, and calculations were made relative to this for all other forms of wood. For the same amount of chemicals used, the cook yields are lower for whole tree chips due to bark, fines and foliage (Wawer 1975).

The washing efficiency deteriorates with poor quality raw material and the soda losses increase. The bark fines and dirt content results in increased use of bleaching chemicals in the bleach plant. This can increase the color bodies, biological oxygen demand and suspended solids to the waste treatment plant. Poor quality chips also effect the strength and brightness of bleached pulp.

Among other problems that effect the overall pulp mill operation are pluggage of screw conveyors, chutes and feeders, corrosion and erosion of equipment, lower pulp strength and more dirt in pulp. These result in increased operating costs and loss in production. Southern mills, principally manufacturing linerboard, have reported that 5% unscreened whole tree chips could be blended with mill chips without experiencing any operating or quality problems (Lowe 1975).

Recovery Cycle

Poorer digester yields with increased chemical usage indicate an increase in black liquor solids that consist of lignin and inorganic chemicals for the same amount of oven dry tons of pulp produced. This results in an overload on the recovery boilers and can become a bottleneck in the overall mill production capabilities.

Also due to increased green tons of chips, the water that needs to be evaporated from the black liquor affects the steam usage at the evaporators. Calcium, silica and other materials in bark and foliage cause scaling of evaporators.

The positive aspect of this situation is a net increase in steam production from the recovery boiler which can offset the more expensive steam generated from power boilers that may be using oil or gas as a fuel.

Paper Mill

The impact of using pulp from whole tree chips on paper machines is basically in production rates, poor quality of product and higher maintenance costs (Conner 1978). Bark and foliage reduce pulp drainage, causing a decrease in machine speed, thereby affecting production. Pitch and waxes from bark can plug felts, reducing their effectiveness and requiring machine downtime for changes. Grit and bark dirt can overload machine cleaners, resulting in production losses and causing roll wear and reduced wire life, thereby increasing maintenance costs.

The quality of the finished product is very important. Poor quality fiber can effect the dirt count, brightness, strength, pinholes, pickouts, etc. and result in increased rejects. Some of these physical properties effect the converting operation that can become a serious problem for the customer.

Power Boiler

The power boiler is probably the ideal place to utilize biomass, provided the costs are justifiable in comparison with other fuels. The heating value of twigs and foliage is less than bark, and the moisture content is relatively higher. Also, grit with screenings from whole tree chips cause more ash, slag and wear on equipment, thereby increasing maintenance and operating costs. With proper blending of this material with bark and other fuels, the use of biomass as a boiler fuel is technically feasible.

FIBER QUALITY ENHANCEMENT

It appears that whole tree and whole stem chips can be blended in certain quantities with clean chips to give an optimum mix that makes economical sense. However, if these chips can be enhanced in quality to get closer to the clean chips, then it may be possible to use these in increased quantities. It is essential that all cleaning of chips be done prior to the pulping process and not after, because of the ease of separating the undesirables before they react with chemicals and steam in the digesters.

Whole Tree Chips

Enhancement must commence in the woods. Portable chippers should be equipped with separators that can reject fines, bark and chip grit and some twigs and leaves. The screening operation for these chips should be a disc-type classifier that not only separates the fines and oversize but also separates twigs and foliage. Storage piles should be turned over quickly, and the chips should be blended in with clean chips at a pre-established rate. The quality of these chips should be constantly checked to ensure the overall quality of the mix.

Whole Stem Chips

Whole stem chipping should follow a similar process to whole tree chipping if they are chipped in the woods; however, since they do not contain twigs and leaves, perforated drum-type screens used in series have proved to be successful in enhancing the quality. If whole stems are not chipped in the woods but brought in as roundwood to a satellite chip mill, then debarking should be done using either a ring debarker, which is a high maintenance item, or a drum debarker. The material can then be chipped and screened in perforated drum-type screens. Before chipping a log washer has proved successful in washing off sand and maximizing chip knife life. After these chips enter the mill, they should be classified and fed to the digesters. All bark and fines from this operation can be burnt in power boilers. If the whole stem is to be chipped in a central mill woodyard, debarking can be accomplished in longwood debarking drums, and then the chips can be screened and classified before entering the digesters.

Clean Chips

Clean chips coming from outside sources, such as saw mills, should be continuously checked for quality. The bark, fines, grit, uniformity of size and moisture should be specified in the contract. Some deviations can be permitted but with monetary penalties to the suppliers. The supplier must understand the need for quality. A strict and continuous quality assurance program may be costly but is worthwhile.

ECONOMIC CONSIDERATIONS

All operations should constantly strive to minimize cost in their areas of activity, thereby maximizing the profitability of the finished product. However, limitations do exist, and one has to carefully analyze and review a given situation from a technical and practical viewpoint and not ignore the resulting economic implications.

Throughout this discussion the detrimental aspects of biomass utilization for pulping have been indicated. Relative indexes have highlighted the effect on mill operations. In analyzing the costs in each of the areas, it appears that the price per green ton of the type of chips supplied to a mill is the most critical item that affects the overall cost of the product (Reside and Garvin, 1978). It should be clear by now that in-mill processing costs will always favor cleaner chips. If, however, the relative savings in raw material costs entering the mill gate offset the incremental in-mill processing costs, then an optimum chip mix exists, thus minimizing the total cost of the product. Generally, the more pronounced the minimum point in raw material cost is, the more dollar savings will be in comparison to a 100% clean chip operation. The optimum chip mix varies with

the situation at each location and gives an opportunity to utilize certain portions of the biomass without upsetting the in-mill operations.

RECOMMENDATIONS

The overall objective is to utilize as much biomass as possible, keeping in mind the economic and technical impact on the entire system that starts from the forests and stops at the paper machine. To fulfill this objective, the following items should be given serious consideration:

- The current techniques of biomass harvesting should be re-evaluated, and a system should be developed to reduce current unit costs.
- Separation of undesirables should be done during harvesting, at a satellite chip mill and in the mill woodyard - in that order.
- Quality assurance and control of chips must be done before chips enter the digester.
- An analysis of the optimal chip mix should be made periodically based on costs, and then barky chips should be blended in with clean chips so that a uniform mix is furnished to the digesters.
- All undesirable material rejected for pulping purposes should be diverted to the power boilers.
- Biomass chip inventories should be kept at a minimum, and piles should be turned over rapidly.

These recommendations result in providing the advantages for the entire system in completely utilizing biomass. The mill ends up with quality controlled fiber. Portions of the biomass can still be utilized for pulping based on optimal economics. The timberlands and wood procurement operations can continue with programs for the total harvesting of the biomass by enhancing harvesting systems that are economical. The separated raw material can be used for the best purpose it is suited for - the branch wood, twigs, foliage, bark and fines being sent to the power boilers for generating steam and the whole stem for pulping, thereby fulfilling the overall objective.

LITERATURE CITED

Karter, E. M.
1974. Mill Experience with Whole Tree Chipping. Fiber Conserv. Utiliz. (Proc. Pulp and Paper Seminar, Chicago) 231-237.

Wawer, A.
1975. Bark in Hardwood Chips - Effect on Mill Operations. Pulp and Paper Canada 7:51-54.

Lowe, K. E.
1975. The Pulp Mill Viewpoint: All is not Rosy with Whole-Tree Chip Picture. Forest Industries. Pulpwood Annual.

Conner, A. L.
1978. Utilization of Whole-Tree Chips in an Unbleached Kraft Linerboard Mill. Southern Pulp and Paper Manufacturer 14-15.

Reside, D. A. and Garvin, B.
1978. Kraft Pulping of Unbarked Chips - A Preliminary Economic Assessment. Tappi 61:5.65-67.

NON FOREST INDUSTRY UTILIZATION OF FOREST BIOMASS[1/]

J. Fred Allen[2/]

Abstract.--Since the 1973 oil embargo, alternate energy sources have been sought by both the private and industrial sector of our society. Wood, while not a new energy source, has been faced with a new generation of potential users. The abundance of Georgia's forest prompted the development of Georgia's Wood Energy Program. While the natural resource, harvesting equipment and wood-burning systems existed, doubt still remained in the non-forest related industries as to using wood for energy. As a result, the Georgia Forestry Commission began establishing wood-burning demonstrational systems at various state facilities. Presently five schools, three correctional facilities, two hospitals and the Forestry Center are designed to burn or are burning wood. The direct and indirect benefits to the tax-payers as a result of these systems have been calculated to be \$2.9 million annually. In addition to this, wood energy in all sectors reflects over a half billion dollar annual benefit both directly and indirectly.

Since the fuel shortage and oil embargo of 1973, attention has been focused on the basic resources essential to the well-being of the United States. Until the introduction of cheap fossil fuels, wood was the main source of energy in the nation and now, for the first time in many decades, has the potential to become a viable alternate fuel source. With today's prices for oil, coal, gas and electricity, many industries, small businesses, public facilities and homeowners are converting to wood as a more economical fuel source. Our forests offer us not only a renewable but expandable fuel--one that could greatly reduce our dependency on foreign and other domestic energy sources.

Wood-fired sytems have been in widespread use in the forest products industry for several years. The American Pulpwood Association indicates that today 64 percent of all energy used by their Georgia industries comes from the forest in the form of bark, residue, whole tree chips and spent liquors from the pulping process. The number of forest industries using all of their wood waste and generating most of their energy needed to operate their plants is growing. Currently in Georgia, studies indicated that only four percent of our forest processing plant residue is not being utilized.

Wood for energy has proven itself within the forest industry where it was not only an economical fuel but also a method of disposing of plant residue. Outside the forest industry, wood as an energy source was and is looked upon very cautiously. While wood is not a new source of energy, a new generation is the potential user. Wood energy is not the ''cure all'' nor is it suited for every circumstance, but where applicable, it becomes a very attractive alternate energy source. The conversion from conventional fuel sources to wood was and is a matter of survival for many industries and small businesses faced with fuel scarcity and unstable prices. While the capital outlay required for a wood-fired system and handling is somewhat more substantial than conventional fuel systems, the payback periods as a result of fuel savings are often very impressive.

1/Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

2/Chief, Forest Research, Georgia Forestry Commission, P. O. Box 819, Macon, Georgia 31298-4599.

Once a potential user of wood deems the conversion profitable, the question arises as to the current and future supplies and the associated cost. The availability of fuel will depend upon the location of the system and other wood users within the market area. As with most commodities the price will be dictated by demand. When the cost of wood equals or exceeds the cost of conventional fuels, one would expect the user to revert back, primarily due to the convenience associated with fossil fuels.

To promote wood energy in Georgia and to demonstrate to non-forest related industries that wood can work for them, the Georgia Forestry Commission began establishing wood-fired systems in various public institutions. To date, five public schools have been converted to wood heat, replacing existing oil, gas or electrical systems. In that these systems are only operational for a period of four to five months, the payback period is somewhat longer than in other public facilities. The schools are supplied by local sawmills. Chips are delivered to the schools by 20-ton live bottom vans where in-ground hoppers are installed or in farm silage wagons mounted on trucks.

Two state correctional facilities have been converted and one new facility was designed to utilize a wood energy system. At the Georgia Industrial Institute, two 15,000 pounds of steam boilers are installed and designed to replace 23 separate boilers. The Dodge and Walker Correctional Institutes are anticipating a payback through fuel savings in five years. It is estimated that the prisons should save the taxpayers approximately 30 percent over the cost of gas and oil. In addition, it should provide some vocational training for certain inmates to learn how to operate boiler systems.

At Northwest Georgia Regional Hospital in Rome, a 25 million BTU per hour updraft gasifier was retrofitted to an existing 550 h.p. boiler. Wood gasification is still in the early stages of advance technology. Since this system was the first of its kind, problems were anticipated and have developed. While the second generation gasifier is benefiting from our design, so are we from their success. Every day the gasifier is on line for 24 hours, the hospital saves $1,000 in fuel costs over natural gas. The hospital at present does not have any formal contracts with the local suppliers but has a working arrangement that is suited to all concerns. As fuel is needed, the hospital contacts various mills. While the mill is not bound to supply a given amount, mill shutdown poses no problems, nor does the hospital have to worry about excess storage if the gasifier is down.

At Central State Hospital in Milledgeville, two 25,000 pounds per hour wood-fired systems will be installed to supply approximately 80 percent of the steam requirement with the remainder being supplied by gas upon demand. The capital outlay for the system and wood handling is $2.5 million. An analysis prepared by a private engineering firm stated that ''The investment in converting to wood-fired boilers is attractive because the net present value of all cash flows is positive. It would still be an attractive investment if the initial cost of the project was an additional $3.8 million.'' The present value of the fuel cost savings in the first six years is $7.6 million. While the system will require a large amount of chips daily, contacts with local total tree harvesters and mill managers indicate that there should be no problem in the supply.

The Georgia Forestry Commission and U.S. Forest Service offices at the Macon Center have converted over to wood heat through the establishment of two hot water systems. Actual fuel savings for 3½ months of operation this year was approximately $11,500. Two wood systems, 30 h.p. and 50 h.p., are utilized so that better efficiency from the individual system can be reached depending on the weather. At the present time, chips are procured on the open market as price dictates.

When all previously mentioned public facilities are fully operational, the taxpayers of Georgia will realize a savings by converting to wood of $1.4 million per year. In addition to this is the economic activity, income and employment that will be created in Georgia as a result of home-grown fuel and not imported. The direct and indirect benefits are estimated to be $1.5 million. This coupled with the fuel savings, will yield an annual economic benefit of $2.9 million to the taxpayers of Georgia.

Within the state there are approximately 90 forestry and non-forestry related industries utilizing wood-fired systems to produce their necessary energy requirements. Twenty industries are non-forestry related, and include public facilities, textiles, concrete block manufacturing and a private college. An example of the non-forest industry converting to wood-fired systems can be seen by such

industries as Burlington, Fairbanks, Integrated Products, Proctor and Gamble, and a U. S. Army installation at Fort Stewart. These users are or will be burning approximately 900 tons of wood material per day replacing the equivalent of approximately 384,000 barrels of oil and 52 million cubic feet of natural gas per year. Mathis-Akin, a concrete block manufacturer, has converted to a 100 h.p. wood system to produce the heat required to cure the block. Truett-McConnell, a Baptist College, has installed a 100 h.p. system to heat several of the buildings. In addition, they have purchased, at a very reasonable price, a 22-inch chipper to produce their fuel requirements and have the potential to act as a broker for other systems within their area.

While forestry and non-forestry related industries in Georgia are utilizing either total tree chips or mill residue to produce their energy requirements, there is another group of users that is playing an important role--the homeowner.

In 1979, a survey of the state was conducted to determine the number of homeowners using firewood. Two years later, the study was updated revealing some significant changes. Based on the 1981 survey, there were some 674,411 homes using firewood which represented a 30 percent increase in the two years. The total annual consumption of firewood rose from 800,000 cords in 1979 to approximately 1.7 million cords in 1981, of which 82 percent was harvested by the consumer. The implied value of wood cut by the user and the value of purchased wood totaled to $135.5 million. Based on the survey, some 400,000 homes plan to install new wood burning equipment, and at current consumption rate, approximately one million additional cords of firewood would be required.

Estimates have been made that 13.1 million tons of roundwood, chips and residue are being utilized in industries, government institutions and households as fuels in Georgia annually. Based on fuel oil valued at 98.2 cents per gallon, it is estimated that the annual fuel savings to wood users to be $494.7 million. In addition, $44.1 million results from additional economic activities arising from the fact that the wood fuel is a ‘‘home grown’’ product as compared to an imported fuel. The combination of these two results in an annual economic benefit to Georgia exceeding a half billion dollars.

As in years gone by, wood is playing an important role in the energy field for both forestry and non-forestry related industries. Wood energy now offers the professional forester one more management tool, and through proper forest management, we can continue to insure the supply of wood required for the forest industries as well as for energy wood.

SESSION 4

LATEST RESULTS IN FOREST BIOMASS SAMPLING, ESTIMATION AND RELATED RESEARCH

Moderator: Michael A. Taras

GREEN WEIGHT AND WOOD AND BARK PROPERTIES OF PONDCYPRESS IN CENTRAL FLORIDA[1/] [2/]

W. Henry McNab, Joseph R. Saucier[3/]

and

Douglas R. Phillips[4/]

Abstract.--Sixty-five pondcypress (*Taxodium distichum* var. *nutans* (Ait.) Sweet) trees ranging from 5 to 18 inches d.b.h. were sampled to determine wood and bark physical properties and green weight of the total tree and its major components. Thirty-nine trees were harvested at one location during December; the others were cut in the same vicinity during July of the next year. Specific gravity, moisture content, and green weight of main stem wood and bark combined did not differ significantly between locations. Main stem weight of green wood and bark per cubic foot of wood averaged 60 pounds. Equations were developed for predicting total-tree and component green weight, dry weight, and cubic volume, from tree d.b.h. and total height.

Cypress (*Taxodium* spp.) is one of the most important commercial forest species of wetland areas in coastal regions of the Eastern United States. Its range extends from New Jersey along the Atlantic and Gulf Coastal Plains to Texas, and north up the Mississippi Valley to Indiana. In the Southeast, cypress accounts for almost 8 percent of all green softwood biomass, and in Florida almost 26 percent of conifer biomass consists of cypress (McClure, Saucier, and Biesterfeldt 1981).

Baldcypress (*T. distichum* (L.) Rich.) is the best known and largest eastern cypress species, reaching a diameter of 8 to 10 feet as measured 1-1/2 feet above the butt swell in virgin stands (Mattoon 1915). Pondcypress (var. *distichum* (Ait.) Sweet), a smaller tree with a range restricted to the lower Coastal Plains, is usually found in shallower swamps of two types, strands and domes. Strands are narrow bands of wetland providing drainage for surrounding areas during wet seasons, while domes are isolated stands usually circular in shape (Nessel and others 1982).

Heartwood from both varieties is used where resistance to rotting is important, including cooperage, boats, posts, and, at one time, caskets. Pondcypress is now typically utilized for decorative paneling, residential fencing and vegetable stakes. Residues are chipped for landscaping mulch.

Although cypress is now commonly marketed by weight scaling, little published information is available on estimation of volume from green weight. Dry weight information is available from academic studies conducted in Georgia (Schlesinger 1978) and Florida (Brown 1981, Burns 1978, and Mitsch and Ewel 1979). Green weight equations presented by Swindel and others (1982) are based only on d.b.h., so the additional accuracy obtained by using the height variable is not available.

This paper is based on results of two pondcypress biomass studies. It reports physical properties of wood and bark, green and dry weights, and volume prediction equations for total trees and major tree components. Product and residue yields from these studies have been reported elsewhere (Phillips and others, In Press).

METHODS

Sixty-five pondcypress trees were selected from even-aged strands at two locations in Volusia

---

[1/] Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, SC, June 15-17, 1983.

[2/] Cooperative study with the Florida Division of Forestry, Forest Utilization Division, Tallahassee, FL, and American Wood Products Company, Longwood, FL.

[3/] Silviculturist, and Project Leader, USDA Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Athens, GA.

[4/] Project Leader, USDA Forest Service, Southeastern Forest Experiment Station, Department of Forestry, Clemson University, Clemson, SC.

County, near Deland, Florida. Pondcypress dominated the canopies of both strands; a lower canopy was formed by maple (*Acer rubrum* L.) and blackgum (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.). Natural stands of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) bordered both pondcypress strands. Basal area in both stands was about 70 square feet per acre. Four to six trees in each stand were selected in each even-inch d.b.h. class from 6 to 18 inches.

The main stem to a 2-inch d.o.b. top of 39 trees was sampled at the first study site in December. During late July of the following year, the main stem and crown of 26 pondcypress were sampled at a second location. The ground water table was abnormally low in the study area during the summer, due to below-average rainfall. Foliage on some small trees had a yellowish appearance, suggesting that these trees were under moisture stress.

Before felling, the crown class of each tree was noted and its diameter was measured at 4.5 feet above ground level (or 1.5 feet above butt swell) to the nearest 0.1 inch with a diameter tape. When each tree was felled, it was measured to determine stump height, height to base of crown, and total height. Diameter of the stump and the stem at the base of the live crown were also measured. The tree was subdivided into two major components: stem and branches. The stem consisted of wood and bark from the stump to the 2-inch d.o.b. top, and included components usually utilized as saw logs, pulpwood, and topwood. Branches included all live branches and tip of the main stem less than 2 inches d.o.b. Dead branches were ignored in this study because of the small number present and because they would probably be broken off during logging operations.

The main stem was weighed in the field to the nearest 2 pounds on a hydraulic load cell. Branch components were weighed in the field to the nearest 0.1 pound on 300-pound-capacity platform scales. Sample disks were systematically collected from the stem and branches of each tree, sealed in polyethylene bags, and returned to the laboratory for determination of physical properties.

Sample disks were processed by standard procedures (Clark and Taras 1976) to determine bark percent on a green weight basis. Specific gravity and moisture content were determined separately for wood and bark samples. Average tree and component properties were calculated by weighting disk sample values by the volume they represented in the tree. False rings (Newlin and Wilson 1917) prevented reliable determination of tree ages, but we estimated average tree age at between 60 and 80 years. Wood and bark properties from the two sample locations were subjected to t-tests to determine if observations were from the same population and could be combined into a pooled data set.

Standard regression analysis was used to develop equations for predicting green weight of the total tree and its components from the independent variables of d.b.h. and total height. Double logarithmic (base 10) transformation was used to achieve a generally homogeneous variance as required for regression analysis. The linearized allometric equation used in data analysis was:

$$\mathrm{Log}_{10}(Y) = a + b *(\mathrm{Log}_{10}(X)) + \mathrm{Log}_{10}(E)$$

where:

Y = tree or component green weight (pounds)
X = d.b.h. squared times total height (D^2Th)
a, b = regression coefficients
E = experimental error

Because logarithmic transformation results in geometric means, instead of arithmetic means, when log values are retransformed back to original units, a correction for downward bias was applied to the intercepts of the prediction equations (Baskerville 1972).

RESULTS

Only green weight data are presented here because this information is most commonly needed by users. Prediction equations, however, are also presented for dry weight and cubic volume of pondcypress. Trees sampled during December at the first location are referred to as the winter plot, while those cut in July at the second location are the summer samples.

Tree Size

Means and ranges in diameter and height of sample trees are presented in table 1 by season of sampling and d.b.h. class. With the exception of trees in the 16-inch class, trees sampled at both locations were similar in average d.b.h. and total height. Trees sampled during the summer in the 16-inch class averaged over an inch larger than trees cut during the winter. Sawtimber-size pondcypress trees sampled during the summer were several feet taller than trees of similar diameter sampled in the winter, especially for the larger d.b.h. classes.

Location Effects

Specific gravity of stem wood was higher for trees sampled in the winter, while bark specific gravity was greater for the summer sample (figure 1). Analysis of mean stem wood and bark specific gravity, using a t-test for unpaired observations, revealed no significant plot location differences at the 5 percent level. Variability in the sample data, especially for trees from the summer plot, as shown by the relatively large standard errors, prevented detection of a significant difference if it was present.

Average moisture contents of stem wood and of wood and bark were inversely correlated with specific gravities of these components. Bark moisture content and specific gravity were directly correlated. Stem bark moisture content was significantly higher among trees sampled at the summer location compared to the winter plot, as shown in figure 1.

Table 1.--Averages and ranges in tree size by d.b.h. class for pondcypress sampled at two locations in Central Florida.

D.b.h. class (in.)	Trees sampled	DBH Mean	DBH Range	Total height Mean	Total height Range
	Number	-----*Inches*----		----*Feet*----	
		WINTER SAMPLES			
6	5	5.9	5.5- 6.1	48.2	34-56
8	5	7.9	7.2- 8.7	61.6	57-64
10	8	10.1	9.1-10.8	68.1	56-78
12	8	12.5	11.8-12.9	65.0	57-70
14	7	14.0	13.0-14.7	67.4	59-76
16	5	15.9	15.2-16.5	69.5	60-76
18	1	17.0	-	71.0	-
Average	39	11.4	5.5-17.0	64.5	34-78
		SUMMER SAMPLES			
6	4	5.8	5.0- 6.5	50.3	46-56
8	4	7.8	7.0- 8.1	55.5	53-58
10	4	9.8	9.2- 9.2	64.8	57-68
12	6	12.0	11.7-12.6	66.3	61-72
14	5	13.6	13.0-14.4	69.6	64-74
16	2	16.8	16.8-16.9	72.0	71-73
18	1	18.1	-	65.0	-
Average	26	11.0	5.0-18.1	61.6	46-74
Average	65	11.2	5.4-18.1	64.0	34-78

Except for a small difference in bark moisture content, no significant location differences were found in wood properties which would bias accuracy of weight scaling results. Therefore, observations from both locations were combined into a pooled sample.

Physical Properties

Presented in table 2 are average values of pooled specific gravity, moisture content, and green weight per cubic foot for wood and bark of the major components of pondcypress. Wood specific gravity was greater in branches than in the stem, and the difference was even greater for bark. Average moisture contents were also slightly greater for wood and bark in the branches than in the stem.

Average green weight per cubic foot of wood and bark was also greater for the branch components than for the stem. Branch wood averaged 2 pounds greater, and branch bark was over 6 pounds greater than for similar stem components. For wood and bark combined, branch green weight per cubic foot was only slightly higher than for the stem.

Tree Components

A t-test indicated no significant difference between locations of sampling for the proportion of tree green weight in branches, or the proportions of stem and branch weight consisting of wood and bark. Green weight data from the two sample sites

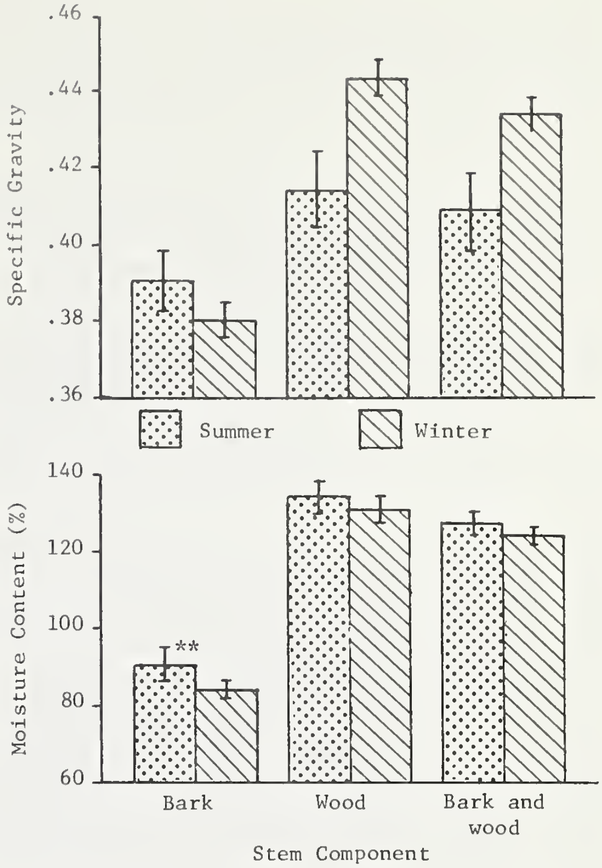

Figure 1.--Average (± 1 standard error of mean) specific gravity and moisture content of pondcypress bark and wood for plots sampled at two locations. Asterisks indicate a significant difference at the 1 percent level of probability.

Table 2.--Average specific gravity, moisture content and green weight per cubic foot of wood and bark for total-tree and components of pondcypress sampled in Central Florida.

Tree component	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	----*Pounds*----
		WOOD	
Branches	0.446	133.1	64.54
Stem	.431	132.7	62.27
Total tree	.432	132.8	62.38
		BARK	
Branches	.435	88.8	51.00
Stem	.382	86.8	44.41
Total tree	.390	87.6	45.30
		WOOD AND BARK	
Branches	.444	118.1	60.03
Stem	.424	126.0	59.64
Total tree	.427	125.8	59.70

were pooled. Table 3 shows pooled mean values of these variables by d.b.h. class. The proportion of green tree weight in branch wood and bark was directly related to d.b.h., and ranged from about 1 percent for 6-inch trees to 10 percent for 16-inch d.b.h. trees.

Table 3.--Average total tree green weight and proportions of total-tree wood and bark in branches and foliage, and proportions of stem and branch green weight in bark by d.b.h. class for pondcypress trees in Central Florida.

D.b.h. class (in.)	Tree green weight	Tree weight in Branches	Tree weight in Foliage	Bark weight in Stem	Bark weight in Branches	Bark weight in Total tree
	Pounds	*Percent*				
6	253	1	5	13	31	14
8	485	3	5	11	29	11
10	926	4	4	10	28	11
12	1445	5	3	9	28	10
14	1710	7	3	10	29	12
16	2106	10	3	10	26	12
18	2346	10	3	11	27	12

Branches had almost 3 times as high a bark percentage as stems (table 3). As tree size increases, bark percentage remains almost constant. Mean bark content was about 10 percent for stems and about 28 percent for branches. For the total tree, average bark content was about 12 percent. Clark and Taras (1976) found similar proportions for the southern pines.

The proportion of above-ground biomass in green foliage was determined for trees sampled during the summer. Expressed as a percent of total-tree wood and bark, average foliage percent ranged from over 5 percent for 6-inch d.b.h. trees to less than 3 percent for 18-inch trees, and averaged 3.4 percent overall. This is slightly less than reported for the southern pines (Clark and Taras 1976).

Weight and Volume

The ratios of stem green weight to cubic foot volume of wood and bark and to wood alone were not correlated with d.b.h. (table 4). Average values of green weight of wood and bark per cubic foot of wood, and per cubic foot of wood and bark, are useful in weight scaling and are given below for major tree components of pondcypress:

	Weight of green wood and bark per cubic foot of Wood	Weight of green wood and bark per cubic foot of Wood and bark
	Pounds	
Branches	88.7	59.7
Stem	69.5	59.9
Total tree	70.5	59.9

The green weight of wood and bark per cubic foot of wood for branches was greater than for the stem, apparently because a large proportion of branch weight consists of bark, which has a high specific gravity.

Table 4.--Average green weight and cubic volume of wood and bark in the main stem of pondcypress by d.b.h. class.

D.b.h. class (in.)	Total stem wood & bark	Volume: Wood & bark	Volume: Wood	Ratio of stem weight to cubic volume of: Wood & bark	Ratio of stem weight to cubic volume of: Wood
	Lbs.	*Cu. ft.*		*Lbs./cu. ft.*	
6	247	4.37	3.36	56.5	68.0
8	467	7.94	6.74	58.8	69.3
10	883	14.43	12.54	61.2	70.4
12	1365	22.74	19.81	60.0	68.9
14	1591	26.58	22.90	59.9	69.8
16	1903	28.62	24.44	66.5	77.9
18	2111	35.05	30.57	60.2	69.0

Prediction Equations

Table 5 contains regression coefficients and sample statistics of prediction equations to estimate green and dry weight and cubic volume of the total tree and its major components. Estimated weights of other components may be obtained by subtraction. For example, weight of green stem bark can be obtained by subtracting estimated weight of stem wood from estimated weight of stem wood and bark. As with results from any biomass research, the user should test these equations for application to trees in the geographical area of interest.

Table 5.--Regression coefficients and statistics for predicting green and dry weight and volume of pondcypress with the regression model $Y=a(D^2Th)^b$

Tree component	Mean Y	Coefficients[1/] a	Coefficients[1/] b	Statistics N	Statistics $S_{y.x}$[2/]	Statistics R^2[3/]
GREEN WEIGHT (Pounds)						
Wood & bark	1199	0.24940	0.93088	26	0.053	97
Wood	1064	.20169	.94108	26	.055	97
Stem wood & bark	1120	.30361	.90242	65	.056	97
Stem wood	1006	.23726	.91770	65	.058	97
DRY WEIGHT (Pounds)						
Wood and bark	533	.10659	.93525	26	.057	97
Wood	461	.07984	.95088	26	.060	97
Stem wood & bark	496	.13122	.90527	65	.062	96
Stem wood	436	.09415	.92721	65	.064	96
VOLUME (Cubic feet)						
Stem wood & bark	18.7	.00640	.87697	65	.059	96
Stem wood	16.1	.00454	.89824	65	.061	96

[1/] "a" coefficient corrected for logarithmic bias.

[2/] Standard error of estimate in $\log_{10}$ form.

[3/] Coefficient of determination.

Prediction equations presented in table 5 are based on d.b.h. and total height and provide accurate estimation of pondcypress biomass. As shown by the coefficients of determination, the two independent variables account for over 97 percent of the observed variation in tree and component green weights. Tables for local application based on d.b.h. alone may be prepared by solving the prediction equations using average tree height for each d.b.h. class. However, local weight tables are not recommended for general use because pondcypress trees at other locations may have different height to d.b.h. relationships which could affect weight estimates.

DISCUSSION

The prediction equations and physical properties of wood and bark in this report should be applicable to pondcypress growing in shallow, acid strands with no source of continuous free flowing water. Trees growing in these conditions tend to be small, short for a given d.b.h., slow growing, poorly formed, and with relatively little butt swell at breast height. Some trees we sampled, which appeared sound, had butt rot extending 10 feet or more up the stem. The user should be especially cautious in applying biomass prediction equations to cypress, because of wide differences in soundness and tree form. Mattoon (1915) points out that baldcypress trees growing near free flowing water sources, or widely fluctuating water levels, tend to have markedly different stem form and often have excessive butt swell.

In comparison to biomass results of southern pines presented by Clark and Taras (1976), pondcypress trees are shorter for the same d.b.h., and trees in larger d.b.h. classes may weigh only half as much as similar-size pines. Pondcypress trees have similar proportions of wood and bark as pines, but lower stem wood specific gravity. However, pondcypress and southern pines both have similar green wood and bark weight scaling conversion factors.

Another question often arises when weight scaling cypress. Some loggers perceive that cypress is heavier during the summer than during the winter because moisture content of the stem is higher. As Taras (1956) points out, even small differences in moisture content can greatly affect green weights. Cypress along with tamarack (*Larix laricina* (Du Roi) K. Koch) differs from other conifers in that moisture content is generally uniform between heartwood and sapwood (Newling and Wilson 1917), and significant seasonal differences in moisture content seem possible.

This study was not designed to evaluate seasonal differences, although bark moisture content was found to be significantly higher in pondcypress sampled during the summer. However, the results of sampling during different seasons in this study could have been confounded. Variation was introduced first by sampling trees at two locations with likely different inherent physical properties, and also by the summer drought. A follow-up study, designed to evaluate seasonal differences is now in progress.

LITERATURE CITED

Baskerville, G. L.
1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2: 49-53.

Brown, S.
1981. A comparison of the structure, primary productivity and transpiration of cypress (*Taxodium distichum*) ecosystems in Florida. Ecol. Monogr. 51(4): 403-428.

Burns, L. A.
1978. Productivity, biomass and water relations in a Florida cypress forest. Chapel Hill, NC: University of North Carolina. 214 p. Dissertation.

Clark, A., III; Taras, M. A.
1976. Comparison of aboveground biomasses of the four major southern pines. For. Prod. J. 26(10): 25-29.

Mattoon, W. R.
1915. The southern cypress. Bull. 272. Washington, DC: U.S. Department of Agriculture; 74 p.

McClure, Joe P.; Saucier, Joseph R.; Biesterfeldt, R. C.
1981. Biomass in southeastern forests. Res. Pap. SE-227. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 38 p.

Mitsch, W. J.; Ewel, K. C.
1979. Comparative biomass and growth of cypress in Florida wetlands. Am. Mid. Nat. 101(2): 417-426.

Nessel, J. K.; Ewel, K. C.; Burnett, M. S.
1982. Wastewater enrichment increases mature pondcypress growth rates. For. Sci. 28(2): 400-403.

Newlin, J. A.; Wilson, T. R. C.
1917. Mechanical properties of woods grown in the United States. Bull. 556. Washington, DC: U.S. Department of Agriculture; 47 p.

Phillips, D. R.; Saucier, J. R.; McNab, W. H.; McCord, J. D.
In Press. Specialty products and residue yields for pondcypress logs. South. Lumberman.

Schlesinger, W. H.
1978. Community structure, dynamics and nutrient cycling in the Okefenokee cypress swamp-forest. Ecol. Monogr. 48(1): 43-66.

Swindel, B. F.; Conde, L. F.; Smith, J. E.; Hollis, C. A. III.
1982. Green weights of major tree species in north Florida pine flatwoods. South. J. Appl. For. 3(2): 74-78.

Taras, M. A.
1956. Buying pulpwood by weight as compared with volume measure. Res. Pap. SE-74. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 11 p.

MACRO ESTIMATION OF FOREST BIOMASS

Joseph D. Kasile

Predictive models of above stump forest biomass were formulated for ground truth data from (1) 25 locations of forest harvest records, (2) six locations of U.S. Forest Service Biomass Inventory estimates, and (3) a combination of both sets of data. LANDSAT digital data consisting of logarithm reflectance values for four channels and the ratios of pairs of log values for these four channels were related to ground truth data using stepwise regression. The log ratio of channels one over three and two over three were the two significant variables with an R^2 = .87 (Probability = .045) for the U.S. Forest Service Biomass inventory. For the harvest records, none of the four channels or their log ratios were significant. For the combined data of all 31 locations, the R^2 was .204 and log of channels 1 and 2 and the log ratio of channel 3 over 4 were included in the model with a probability level of .099.

INTRODUCTION

The development of forest biomass as a fuel for industry has received considerable attention during the past five years. The Ohio Department of Energy is currently seeking a wood-to-ethanol plant as a biomass utilization project (Johnson, 1982). A large scale conversion plant would require large amounts of biomass, and the extensive forests of southern Ohio represent a potential supply.

The cost of transporting biomass from the source to the conversion plant is high. Large area estimates of local supplies of forest biomass are necessary before capital investment decisions are made to build a wood-to-ethanol plant. Such a plant would require a continuous supply of wood fiber from a relatively local area.

Timely and accurate forest biomass data could provide a basis for decisions relative to the raw material supply for such a plant. Computer compatible, satellite collected data may provide the key to a practical inventory of forest biomass if the biomass can be determined through the analysis of such data. The most readily available satellite information has been gathered by the LANDSAT series of satellites. LANDSAT satellites are earth resources monitors which provide repetitive coverage of the earth's surface. Data is collected from the same area of land every eighteen days. Reflected sunlight is detected by an array of sensors in the satellite, converted to analog data, and transmitted to earth-based receiving stations. This data is stored on readily available computer compatible tapes. Indeed, the overwhelming volume of LANDSAT data (over 7,500,000 data cells per 10,000 square mile scene) and their inherent digital forms make the data that much more amenable to computer assisted analysis.

The purpose of this project was to investigate the hypothesis that the spectral qualities of a forested area, as measured by LANDSAT satellites, can be used to estimate forest biomass of the area.

Goodman and Lowe (1981) listed "inventory of local resources" as the number one research issue for planning and management of biomass energy projects. A large scale alternative fuel plant requires an abundance of fuelstock in close proximity to be able to produce fuel at a competitive price. An inventory of local resources can be conducted by several methods, but for large geographic areas, satellite data can prove very cost effective when compared to ground and aerial surveys (Schmidt, 1976).

Baker and Fothe (1975) believed that "separability of forest density classifications could be reasonably expected" from LANDSAT data. Satellite data has already been successfully employed to estimate biomass of grasslands (Rouse et al., 1973; Seevers et al., 1975; Tucker, 1978), the biomass of croplands for harvest predictions (Colwell et al., 1977; Pollock et al., 1979; Holben et al., 1980); and the biomass of salt marsh plants (Hardisky et al., 1983).

The studies which provided the estimates of biomass for grasslands, croplands, and salt marshes were performed on vegetation types of relatively uniform heights. These studies relied on the fact that as biomass increased, the amount of soil visible through the vegetation decreased (Myers, 1970). However, in hardwood forest regions, when leaves are present, canopy closure can mask considerable variation in actual biomass density. Beaubien (1979) commented that winter imagery may help to bring out factors such as density of forest stands.

The Ohio Land Use Inventory (Schaal, 1977) achieved a 95% accuracy for identification of forested areas using an early spring LANDSAT scene before the trees had begun to leaf. Thus if an estimate of the biomass of the forested areas could be made, a quick and inexpensive inventory of forest biomass would be possible.

The LANDSAT multispectral scanner system (MSS) detects reflected sunlight with 24 detectors, six detectors in each of four wavelength bands. The system uses an oscillating mirror that scans a 185 km swath of the earth's surface. The instantaneous field of view of the MSS is a 57 meter by 79 meter ground resolution element or pixel. Information is recorded from the .5-.6 micrometer (green), .6-.7 micrometer (red), .7-.8 micrometer (near infrared), and .8-1.1 micrometer (infrared) region of the electromagnetic spectrum. For purposes of this study they were labeled bands 1, 2, 3, and 4, respectively.

These four LANDSAT bands plus the log ratios of these bands were used as the independent variables in trying to predict forest biomass. According to Lyon and George (1979) and Moik (1980) a ratio of LANDSAT bands minimizes the effects of different illumination of different slopes, while subduing the effects of path radiance and enhancing subtle spectral variations.

STUDY AREA

Study sites were located in the forested region of southern Ohio in the Wayne National Forest, in the Central Hardwoods Region. Harvest records were obtained from 25 recent clearcuts of 14 to 48 acres within this area. In addition, the U.S. Forest Service Northeastern Forest Experiment Station provided Forest Survey data for six one-acre plots in the same geographic area.

The U.S. Forest Service provided copies of their sale records for both sawlogs and pulpwood. On sites harvested with whole tree chippers, the sawlog volume was converted to green weight using eight pounds per board foot and then added to the total pulpwood weight on a per acre basis. Previous inventory records compiled by the U.S. Forest Service comparing similar sites indicated approximately 5 tons more per acre of biomass were harvested utilizing whole tree chippers than from non-whole tree chipper operations (Schoener, 1982). Thus for non-whole tree chipper sites, an additional five tons per acre was added to the sawlog and pulpwood weight to account for unutilized tops and branches. Actual total biomass weights ranged from 41 to 100 tons per acre for harvest sites, and from 55 to 171 tons per acre on the forest inventory data.

Since pixel registration between the satellite data and the tree ground location may not be perfect, it was believed that tracts containing a minimum of 40 pixels were necessary to allow for some misidentification. For this reason, aerial photographs of scale 1:40,000, taken October 5, 1974, were used to delineate homogenous tracts of at least 40 pixels that included the locations of the clearcut and inventory sites. Thus, the area of each sample image was at least 44 acres, since a 57 meter by 79 meter pixel images approximately 1.1 acre.

A pixel print of a subscene (lines 1170 to 2200, samples 1626 to 2325) of LANDSAT scene 8269215183500 was obtained from the EROS Data Center, Sioux Falls, South Dakota. The data were collected by LANDSAT II on December 14, 1976. The data were preprocessed with the Electronic Data Image Processing System (EDIPS) to correct for geometric distortion and radiometric miscalibration prior to purchase. A winter scene was chosen so that spectral contrast would exist to differentiate between different tree densities and the ground underneath. In addition to density, the reflectance values should also be influenced by tree height, as taller trees will produce more ground shadow. LANDSAT images are collected every 18 days at the same time of day.

Digital data values were converted to reflectance values following the procedures described by Robinove (1982). This standardizes the digital data. The reflectance values were converted to their logarithmic form. Log values were then ratioed for each of the six combinations of the four channels. The log form was used because this permits good separation of the ratioed values, regardless of which channel is chosen for the numerator or denominator (Moik, 1980). The six ratio combinations used for this study were: channels 1/2; 1/3; 1/4; 2/3; 2/4; 3/4. The reflectance values for the four channels and the six ratio combinations for each pixel were

then used to compute an average value in each of the parameters for each site.

Stepwise multiple regression (SAS, 1980) maximum R^2 analysis was used to develop a predictive model for three combinations of the data: (1) using the 25 harvest records, (2) using the six U.S. Forest Survey plots, and (3) combining all 31 data records. The five percent level of significance was used for variable inclusion in the model.

RESULTS AND DISCUSSION

The forest biomass regression models that were generated are:

Clearcut Harvest Sites

Biomass (tons/acre) = 13.38

- 42.50 (log channel 4)

+ 117.18 [log (channel 1/channel 3)]

- 84.26 [log (channel 2/channel 4)]

R^2 = .046 (P > 0.08010)

Forest Survey Plots

Biomass (tons/acre) = 404.25

+ 2.315.91 [log (channel 1/channel 3)]

- 4053.15 [log (channel 2/channel 3)]

R^2 = .87 (P > 0.0446)

Combined Data

Biomass (tons/acre) = -156.97

+ 3958.64 (log channel 1)

- 3394.01 (log channel 2)

- 181.29 [log (channel 3/channel 4)]

R^2 = .804(P > 0.0986)

For the forest harvest records, the model equation included channels 4 and ratios of channels 1/3 and 2/4 and had an R^2 = .046 which was not significant (P > .0801); thus reflectance values for all four LANDSAT channels were included in the model.

For the six Forest Survey plots, the model equation included ratios of channels 1/3 and 2/3 and had an R^2 = .87, significant at .045. Although the next variable to be added to the equation was channel 4, it was not significant; although the R^2 increased to .96. Combining all data, the R^2 was .804 and the model included channels 1 and 2 and the ratio of channels 3/4. The combined data model equation was not significant, with a probability level of .099.

Variation in the forest biomass as represented by the U.S. Forest Survey data has a strong relationship to reflectance characteristics of the area as monitored by LANDSAT. However, since only six observations were available for this data, the experimental result is subject to reasonable doubt.

The model generated for the forest harvest sites was not significant. The range of data for the harvest sites was less than that of the U.S. Forest Survey data and may have limited the power of the regression analysis to determine a significant relationship between LANDSAT reflectance values and forest biomass. Non-significance of the regression relationship could be due to non-homogeneity of the harvest areas, inconsistencies in the harvest records, or perhaps no strong relationship exists between forest biomass of southern Ohio and LANDSAT digital reflectance data. It could also be due to the inability of LANDSAT digital data to differentiate stand height adequately.

For fully stocked natural stands, stand height is probably more highly correlated to forest biomass than is stand density, as stand height more adequately reflects differences in site quality than does stand density. Site quality indicates the biomass productivity potential of the forest. Since site quality of the harvest site is unknown, differences in site quality for stands of similar density could account for differences in forest biomass that could not be detected by the reflectance values measured by LANDSAT. Also information relative to stand age was not available ; thus in addition to differences in height due to site quality for stands of similar age, differences in age for stands of similar site and density could account for stand height differences. The disparity between the results based on the two separate methods of forest biomass determination may reflect these stand height differences for sites of similar density. The inconsistency of the results of the two data sets suggests that the two data sets should not be evaluated together. The combined data model should not be used.

RECOMMENDATIONS

If results based on the Forest Survey data are accepted, the following procedure could be used to generate macro estimates of forest biomass. Use LANDSAT to separate the various land use categories as described by Anderson,

et. al. (1976). Then, considering only the LANDSAT pixels that were determined to be hardwood forests, generate the log values for these LANDSAT pixels and calculate the ratios of channels 1/2 and 2/3. The predictive equation determined from the Forest Survey data could then be applied to these hardwood forest pixels to produce a pixel by pixel estimate of the forest biomass. A map should then be generated to show location of estimated forest biomass as well as tabled values for specific areas.

SUMMARY

LANDSAT digital data was used in southern Ohio to develop forest biomass predictive models for two data sets: (1) harvest clearcut records and (2) Forest Survey measurements. Stepwise regression using pixel by pixel printouts of log values of the four channels of LANDSAT and the paired ratios of these log values produced a significant model equation for the six Forest Survey data measurements ($P > .045$) but the analysis of the 25 records of harvest clearcut data did not produce a significant equation.

Since only six data points were available for the forest survey records, the practical usage of the predictive model is open to question even though the model was significant. More extensive studies are warranted to pursue this indicated relationship between LANDSAT digital data reflective values and hardwood forest biomass.

LITERATURE CITED

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Whitum. 1976. A land use and land cover classification system for use with remote sensing data. U. S. Geological Survey Professional Paper 964. Washington, D. C.

Barker, G. R., and T. P. Fethe. 1975. Operational conditions for the application of remotely sensed forest data from landsat or other airborne platforms. NASA Earth Resources Survey Symposium, Vol. 1-A, Paper A-20: 115-134.

Beaubien, J. 1979. Forest type mapping from landsat digital data. Photogrammetric Engineering and Remote Sensing 45:1135-1144.

Colwell, J. E., D. P. Price, and R. F. Nalepka. 1977. Wheat yield forecasts using landsat data. Proc. of XI International Symp. on Remote Sensing of the Environment. Ann Arbor, Mich.:1245-1254.

Goodman, L. J. and R. N. Lowe. 1981. Biomass Energy Project, Planning and Management. Pergamon Press, New York, New York.

Hardisky, M. A., V. Klemas, and R. M. Smart. 1983. Seasonal Spectral Characteristics and Above Ground Biomass of the Tidal Marsh Plant.

Holben, B. N., C. J. Tucker, and C. Fan. 1980. "Spectral assessment of soybean leaf area and leaf biomass. Photogrammetric Engineering and Remote Sensing 46:651-656.

Johnson, G. 1982. Personal Communication. Dept. of Energy, State of Ohio, Columbus, Ohio 43210.

Lyon, J. G. and T. George. 1979. Mapping vegetation communities in the gates of the Arctic National Park, Alaska. Proc., Annual Convention of the American Soc. of Photogrammetry, Washington, D. C.:483-497.

Moik, J. G. 1980. Digital Processing of Remotely Sensed Images, NASA (SP-431), Washington, D.C.

Myers, V. L970. Soil water and plant relations. Remote sensing with special references to agriculture and forestry. National Acad. of Sciences, Wash., D. C.:253-297.

Pollock, R. B., and E. T. Kanemasu. 1979. Estimating Leaf-Area Index of Wheat with Landsat Data. Proceedings, XIII Remote Sensing of the Environment, p. 307-312, Ann Arbor, MI.

Robinove, C. J. 1982. Com-utations with Physical Values from Landsat Digital Data. Photogrammetric Engineering and Remote Sensing, Vol. 48, pp. 781-784.

Rouse, J. W., R. H. Haas, J. A. Schell, and D. W. Deering. 1973. Monitoring Vegetation Systems in the Great Plains with ERTS. Third ERTS Symposium Abstracts, NASA, Washington, D. C., 20 pages.

SAS. 1980. SAS Users Guide. SAS Institute, Inc., Box 8000, Cary, North Carolina 27511.

Schaal, G. 1977. Ohio land use inventory final report. Ohio Dept. of Natural Resources.

Schmidt, N. F. 1976. Ohio statewide landuse inventory. Bendix Corp., Ann Arbor, MI.

Schoener, R. 1982. Personal Communication. District Forest Ranger, Wayne National Forest, Ironton, Ohio.

Seevers, P. M., J. V. Drew, and M. P. Carlson. 1975. Estimating Vegetative Biomass from Landsat-1 Imagery for Range Management. NASA Earth Resources Survey Symposium, Vol. 1-A, Paper A-1, pp. 1-8, NASA, Washington, D. C.

Tucker, C. J. 1978. A comparison of satellite sensor bands for vegetation monitoring. Photogrammetric Engineering and Remote Sensing 44:1369-1380.

Salaries and research support provided by State and Federal Funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Journal Article No. 165-82.

Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

Author is Associate Professor, Forestry Division, School of Natural Resources, Ohio State University, Columbus, Ohio 43210

BIOMASS YIELDS OF YOUNG HEAVILY STOCKED SLASH PINE STANDS IN NORTH FLORIDA[1/]

M. S. F. Campbell, C. W. Comer, D. L. Rockwood, and C. Henry[2/]

Abstract.--Nine and eight test plots, respectively, were established in six- and ten-year-old slash pine stands. The maximum total tree dry weight yields were 13.3 mt/ha/yr at 9,800 trees/ha for age 6 and 9.8 mt/ha/yr at 6,200 trees/ha for age 10 trees. Density had a negative effect for all tree components in predictive equations.

INTRODUCTION

Florida is ideal in many respects for growing woody crops for energy due to its favorable climate and large available land base. Several native and introduced tree species have potential for use in such systems, and preliminary investigations into their relative values as biomass crops have recently been initiated (Rockwood et al. 1981). There is also industrial interest in forest biomass as a fuel source.

Slash pine (*Pinus elliottii* var. *elliottii* Engelm.), indigenous to many northern sections of the state, is currently used extensively in commercial pulpwood and timber operations in the southeastern USA and in several other countries. Due to its relatively rapid growth, suitability to a large land area, and ease of culture, including nursery practices, slash pine is a potential biomass candidate in Florida (Rockwood et al. 1981). However, there are several unknown elements regarding management of slash pine for biomass production, such as what stocking density and stand age will maximize yield. Several tests have been established in north-central Florida to study density, age, and yield relationships, but these plantings will take five to ten years to provide preliminary information about stocking and age effects on slash pine stand biomass yields.

MATERIALS AND METHODS

Seventeen field plots were selected from aerially seeded stands of slash pine located in Taylor and Lafayette Counties, Florida (Table 1). The plots were selected on the bases of high stocking density, uniform distribution of stems, and a surrounding 3-meter wide buffer strip of equivalent stocking density. Plot area was 100 square meters, with plot dimensions of either 10 x 10 or 8 x 12.5 meters, governed by the uniformity of spacing in the plot.

Following plot establishment, DBHs of all trees were measured. In the buffer area surrounding each plot, 10 to 11 trees were selected for destructive sampling in proportion to the frequency within two-centimeter diameter classes. The basal and breast-high diameters of selected trees were recorded to the nearest millimeter after which the trees were felled at the ground-line to obtain fresh and dry foliage, branch, and bole weights. Bole diameter at the base of the live crown, height to the live crown, and total tree height were then recorded. One randomly selected branch was removed from each whorl and stripped of it's needles. These selected branches were bulked for each sample tree, fresh weights were taken using triple beam swing balances, and the branches (or a random subsample of the branches, depending upon the sample size) were bagged. This process was repeated for the foliage from the sampled branches. All live branches and foliage remaining on the tree were then removed and bulk weighed on a field platform balance. Dead branches were removed and weighed on a triple-beam balance. After the bole was quartered, a sample disc 5 to 10 cm in height was removed from the base of each quarter and from breast height, weighed, and bagged in polyethylene for laboratory processing. The remaining bole was weighed in bulk on a platform balance.

[1/] Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2/] Graduate Assistant, University of Florida, School of Forest Resources and Conservation, Gainesville, FL, 32611; Assistant Research Scientist, University of Florida, School of Forest Resources and Conservation, Gainesville, FL, 32611; Associate Professor, University of Florida, School of Forest Resources and Conservation, Gainesville, FL, 32611; Lands and Timber Research Manager, Buckeye Cellulose Corporation, Perry, FL.

Table 1.--Slash pine study plot characteristics and yields.

Age	Trees per Hectare	DBH Mean	DBH Range	Dry Weight Yields Tree	Dry Weight Yields Bole	Dry Weight Yields Branch	Dry Weight Yields Foliage
(yrs)		-------(cm)-------		------------(mt/ha)------------			
6	6,400	7.3	3.3 - 12.2	74.3 (12.3)[1/]	56.0 (9.3)	8.2 (1.4)	9.6 (1.6)
	7,100	7.1	2.1 - 12.7	75.5 (12.5)	56.9 (9.5)	8.3 (1.4)	10.5 (1.8)
	9,800	6.5	2.3 - 11.4	79.7 (13.3)	60.7 (10.1)	8.8 (1.5)	10.4 (1.7)
	23,600	4.1	0.8 - 8.6	53.9 (9.0)	40.7 (6.8)	5.2 (0.9)	7.2 (1.2)
	26.100	2.7	0.6 - 6.1	23.1 (3.9)	16.7 (2.8)	2.3 (0.4)	4.2 (0.7)
	27,000	3.5	0.8 - 7.6	42.2 (7.0)	31.4 (5.2)	4.1 (0.7)	6.3 (1.1)
	29,000	2.9	0.8 - 6.5	28.8 (4.8)	21.1 (3.5)	2.9 (0.5)	4.9 (0.8)
	33,400	2.3	0.6 - 5.5	19.0 (3.2)	13.7 (2.3)	1.9 (0.3)	3.4 (0.6)
	36,100	3.1	0.6 - 6.5	40.1 (6.7)	29.8 (5.0)	3.8 (0.6)	6.4 (1.1)
10	6,200	8.1	3.0 - 15.5	97.5 (9.8)	74.9 (7.5)	10.7 (1.1)	11.7 (1.2)
	6,700	7.7	0.8 - 13.4	92.0 (9.2)	70.5 (7.1)	10.0 (1.0)	11.0 (1.1)
	8,400	7.3	1.9 - 14.3	96.0 (9.6)	73.8 (7.4)	10.2 (1.0)	11.5 (1.2)
	10,000	7.0	1.5 - 12.4	94.2 (9.4)	72.2 (7.2)	9.9 (1.0)	12.2 (1.2)
	10,100	6.4	1.1 - 12.0	80.0 (8.0)	61.0 (6.1)	8.4 (0.8)	10.4 (1.0)
	11,900	5.5	1.3 - 10.2	68.3 (6.8)	51.7 (5.2)	7.2 (0.7)	9.6 (1.0)
	12,000	5.7	0.7 - 11.6	77.0 (7.7)	58.9 (5.9)	7.9 (0.8)	10.8 (1.1)
	12,200	5.9	1.4 - 14.9	76.5 (7.7)	58.3 (5.8)	7.9 (0.8)	10.7 (1.0)

[1/]Mean annual increment in mt/ha/yr.

The bagged branch and foliage material was d at 70°C until constant weights resulted. bole sample discs were sent to the Buckeye ulose Corporation's Research Center in Perry, Florida, for determination of wood properties at 70°C. Disc and bark specific gravities and volumes were determined by water displacement methods.

Inside bark tree log volumes were calculated with the aid of STX 3-3-73 (Grosenbaugh 1974). Mathematical modifications to the program were used in order to calculate outside bark log volumes. Tree bole dry weight was computed by summing total wood dry weight and total tree dry bark weight (calculated by using wood and bark volumes and specific gravities) for each tree.

Regression analyses were performed to estimate total tree and tree component dry weights by the use of Statistical Analysis Systems (SAS Institute, 1979). Height was not used as an independent variable in these equations because the plot data did not include individual tree heights. Selected equations were applied to the inventory data for each plot to produce total tree and tree component dry weight estimates and per hectare yield figures. Derived yield figures were utilized in regression analyses of yield.

RESULTS AND DISCUSSION

The 171 sample trees from both age classes averaged 5.7 cm in DBH and 6.32 m in total height (Table 2). The average total tree dry weight of 7.36 kg was composed of 5.61, 0.85, and 0.87 kg, respectively, for the bole, branch, and foliage components. Plot densities ranged from 6,200 to 36,000 trees/ha. The average DBH of all 2,760 sampled trees from all the plots was 4.3 cm with a range from 0.6 to 15.5 cm (Table 1).

Table 2.--Population characteristics for 171 destructively sampled slash pine trees.

Characteristic	Mean	Range	Standard Deviation
DBH (cm)	5.7	0.9 - 16.1	2.9
Height (m)	6.32	1.65 - 11.50	2.49
Stocking (Trees/ha)	16,575	6,200-36,100	10,231
Total Tree Dry Weight (kg)	7.36	0.05 - 56.75	9.36
Bole Dry Weight (kg)	5.61	0.02 - 39.34	6.93
Branch Dry Weight (kg)	0.85	0.01 - 10.46	1.34
Foliage Dry Weight (kg)	0.98	0.01 - 7.89	1.20

Of the regression models and regressors examined for tree biomass prediction, the allometric equation utilizing DBH and trees per hectare was superior as a predictor of tree dry weight (Table 3). Coefficients for DBH and density were highly significant at the .01 level. Increased stocking (trees per hectare) had a negative effect upon total tree and tree component dry weights, which agrees with observations of other pines (Satoo 1967; Madgwick and Krek 1980). A negative response to stocking for foliage was a response also observed with *Pinus strobus* L. (Kittredge 1944). Similar results for the bole were observed in *Alnus rubra* Bong. by Smith and DeBell (1974) and in *P. banksiana* Lamb. by Doucet et al. (1978). A negative response of stem form to increasing density levels may account for this observed result. Although this relationship has not been shown in slash pine, van Laar (1978) working with *P. patula* at densities from 125 to 3,000 stems per hectare found that at a given DBH and height tree forms become narrower with increasing density. For a tree of average diameter at densities from 6,200 to 36,100 trees/ha, the decrease in dry weight was 43% (4.9 to 2.8 kg), 59% (0.75 to 0.31 kg), and 51% (1.01 to 0.49 kg) for the bole, branches, and foliage, respectively. The branch component was affected most by increasing density while the foliage was intermediate in degree of response. This disparity in the response of the separate crown components may be due to increased natural pruning with increasing density and to crown component dry weight variation between portions of the crown (i.e., top, middle, and bottom).

Peak stand dry weight yields of all components except foliage on the age 6 plots occurred at 9,800 trees/ha (Table 1). Total tree dry weight yield at that density was 79.7 mt per hectare and bole and branch yields were 8.8 and 10.4 mt per hectare, respectively. The maximum foliage yield value of 10.5 mt per hectare occurred on the 7,100 trees/ha plot although the 10.4 mt per hectare on the 9,800 trees/ha plot closely approached the maximum yield value. The minimum yield values for total tree and all tree components occurred at the 33,400 trees/ha density. The minimum yields were approximately one-quarter of the maximum yields, indicating a strong influence from stocking. Yield figures fluctuated as density increased above 23,600 trees/ha.

Soil sampling revealed that the soils were similar in pH, organic matter content, and horizonation on all plots and classifiable as medifibrists. The similarity of plot soils and their proximity to one another discounts the role of soil in the yield figure fluctuations. However, soil moisture was a possible cause of the observed variation in yield since the higher yielding plots with 23,600, 27,000, and 36,100 trees/ha were located within 15 meters of well maintained drainage canals.

Table 3.--Slash pine predictive dry tree weight and stand yield equations.

Tree Weight Equations

Model $Y = e^{[b_o + b_1 \text{ Ln DBH} + b_2 \text{ Ln Density}]}$

Y	b_o	b_1	b_2	R^2	FI	$Se_{y.x}$	Est. t b_1	Est. t b_2
---(kg)----								
Total Tree	0.045	2.33	-0.27	0.98	0.95	2.06	67.15	-43.73
Bole	0.060	2.43	-0.32	0.96	0.91	2.14	60.43	-44.65
Branch	0.080	2.22	-0.49	0.95	0.84	0.55	47.92	-60.04
Foliage	0.200	1.91	-0.41	0.87	0.83	0.50	26.18	-32.43

Stand Yield Equations

Model $Y = b_o + b_1 \text{ Age} + b_2 \text{ (Density/1000*Age)}$

Y	b_o	b_1	b_2	R^2	CV	Est. t b_o	Est. t b_1	Est. t b_2
---(kg)----								
Total Tree	51.79	6.39	-0.31	0.89	14.0	4.19	5.38	-6.95
Bole	41.76	5.32	-0.28	0.91	14.0	4.31	5.73	-7.91
Branch	6.43	0.71	-0.04	0.92	13.3	5.05	5.78	-9.09
Foliage	7.80	0.74	-0.04	0.89	12.5	5.10	5.07	-7.01

10 yields peaked on the 6,200 trees/ha 97.5 mt total tree dry weight. Mean :ncrements (MAI) of biomass components ear-old stands decreased from the MAI f the 6-year-old stands. At age 6, MAI ! as density increased beyond 10,000 while at age 10 MAI decreased beyond ·es/ha. In contrast with these data, e volume yield tables by Dell et al. t lower age 10 densities than those ·re (1,100 to 2,300 trees/ha), indicate MAI with increasing density and age rs. Similarly, Mann (1971) examined ld data for slash pine with stocking '23 trees/ha at age 14 years and at maximum volumes were obtained by densities on the better sites. The suggest that slash pine MAIs will ·t a lower age with increasing itionally, increasing density beyond ·vel (the value of which decrease ;ults in declining MAI. Since the mum MAI in relation to age cannot from this study, it is difficult ·imal rotation length and stocking ısh pine. However, since biomass yield for age 6 was greatest on the plot with 9,800 trees/ha at age 6, it can be expected that slash pine productivity will peak at an age less than 6 years and at densities greater than 10,000 trees/ha. Our data indicate that slash pine yields are maximized at a density of roughly 10,000 trees/ha at age 6. Based on Mann's (1971) findings and this study, age 10 maximum yields are expected to occur between 4,200 and 6,200 trees/ha.

Age and density best estimated per hectare dry weight yield (Table 3) with density by age having a negative effect and age having a positive effect. A curvilinear relationship between yield and age and density was found. The coefficients for the intercept, age, and age by density cross product in the stand equations were highly significant at the .01 level.

Other biomass yields for slash pine and other southern pine were compared with these results. Manis (1977) working with slash pine on soils similar to those of this study and densities of 1,330 and 1,050 trees/ha at ages 5 and 9 years, respectively, estimated total tree

dry weight MAI to be 0.42 mt per hectare per year for the age 5 stand and 1.88 mt per hectare per year for the age 9 stand. Stands at these densities are understocked even for pulpwood utilization but when viewed from the perspective of the data from this study indicate the increase in yield is due to increased stocking. Frampton (1980) presented data from stands ranging from 8 to 11 years in age with stocking levels that best estimate the densities from 10,000 to 23,000 trees/ha not available in this study's data for age 6 stands but exceed the highest levels for the age 10 stands. These stands had MAIs ranging from 12.4 to 30.7 mt per hectare per year, which were much higher than those MAIs found in this study. Frampton's predicted yield figure for 14,800 trees/ha plot at age 10 was nearly three times that for this study's age 10 plot at 12,000 trees/ha. This large difference is most likely due to site, fertilization, and planting stock differences, illustrating the slash pine biomass yields possible with site preparation and genetic selection, but not necessarily indicating increased yield due to increased stocking.

CONCLUSIONS

Increasing stocking negatively influenced dry weight yields of all tree components. The branch component was the most strongly affected while the bole portion was the least affected. The significance of the density parameter in the individual tree weight estimation equations indicated the advisability of using stand density as an independent variable in biomass models dealing with high density stands.

At age 6 the highest yields obtained on medifibrist soils were for densities near 10,000 trees/ha. At age 10 maximum yields are predicted to occur between 4,200 and 6,200 trees/ha. Peak mean annual increment can be expected to occur at an age younger than 6 years and at densities greater than 10,000 trees/ha.

Regression equations were estimated using sample trees, and these equations were applied to selected plots of 6- and 10-year-old slash pine to predict dry weight yields. Because data for age 6 densities are limited and only two age classes available, further work needs to be done to refine these equations.

ACKNOWLEDGEMENTS

Funding for this project was provided by Oak Ridge National Laboratory, through subcontract No. 9050. These results are also derived from a project that contributes to a cooperative program between the Institute of Food and Agricultural Sciences of the University of Florida and the Gas Research Institute, entitled "Methane from Biomass and Waste." Field work aid provided by G. K. Darfus, J. C. Higman, B. Cuthbert, V. Murrey, R. Dixon, J. Watts, T. Mierzejewski, and M. Shelton is gratefully acknowledged.

LITERATURE CITED

Dell, T. R., D. P. Feduccia, T. E. Campbell, W. F. Mann, Jr., and B. H. Palmer. 1979. Yields of unthinned slash pine plantations on cut-over sites in the West Gulf region. USDA For. Serv. Res. Pap. SO-147, 84 p.

Doucet, R., J. V. Berglund, and C. E. Foornsworth. 1976. Dry matter production in 40-year-old *Pinus banksiana* stands in Quebec. Can. J. For. 6:357-367.

Frampton, L. J., Jr. 1981. Genetic variation of traits important for energy utilization in sand and slash pines. Unpubl. Masters Thesis, School of For. Res. and Cons., Univ. Fla., Gainesville, 135 p.

Grosenbaugh, L. R. 1974. STX 3-3-73: Tree content and value estimation using various sample designs, dendrometry methods, and V-S-L conversion coefficients. USDA For. Serv. Res. Pap. SE-117, 112 p.

Kittredge, J. 1944. Estimation of the amount of foliage of trees and stands. J. For. 42:905-912.

Manis, S. V. 1977. Biomass and nutrient distribution within plantation and natural slash pine stands on wet coastal sites. Unpubl. Masters Thesis. School of For. Res. and Cons., Univ. Fla., Gainesville. 61 p.

Mann, W. F., Jr. 1971. Early yields of slash pine planted on a cut-over site at various spacings. USDA For. Serv. Res. Pap. SO-69, 16 p.

Rockwood, D. L., L. F. Conde, and R. F. Fisher. 1981. Maximizing woody biomass production in Florida. p. 859-867. *In* 1981 International Gas Res. Conf. Proc., Los Angeles. Government Institutes, Inc. P.O. Box 1096, Rockville, MD 20850.

Rockwood, D. L., C. W. Comer, L. F. Conde, D. R. Dippon, J. B. Huffman, H. Riekirk, and S. Wang. 1983. Final report: Energy and chemicals from woody species in Florida. Oak Ridge Natl. Lab. Project 9050, 201 p.

SAS Institute. 1979. SAS User's Guide, 1979 Edition. SAS Inst. Box 8000, Cary, NC, 494 p.

Satoo, T. 1967. Primary production relations in woodlands on *Pinus densifolia*. p. 52-80. *In* Symposium on Primary Productivity and Mineral Cycling in Natural Ecosystems. Ecol. Soc. Amer. AAAS. Univ. Maine Press,

Orono.

van Laar, A. 1978. The growth of unthinned *Pinus patula* in relationship to spacing. So. Afr. For. Jour. N.R. 107:3-11.

GENERATING TOTAL TREE HEIGHTS BY A MONTE CARLO TECHNIQUE[1/]

Tiberius Cunia, John Michelakackis and Sanghoon Lee[2/]

Abstract.--Provided a realistically constructed forest biomass population of trees is available, one can simulate (1) selection of sample trees by various sampling procedures, (2) construction of biomass tables or regression functions by various statistical techniques and (3) application of the biomass tables to the forest population of trees to verify how valid the data-based statistical inferences (bias and precision) are. To construct a population for which the trees are measured for diameter, total height and biomass, one can start with a population of trees measured for diameter and characteristics other than total height and by Monte Carlo procedures generate the total height and then the biomass of each population tree. The paper describes a procedure for generating the total height y by a formula of the form $y=\hat{y}+q$ where $\hat{y}=r(d,h)$ is the estimate of the conditional average total height for trees of given diameter d and merchantable height h, and q is a random variable representing the difference between actual height y and conditional average height $\hat{y}$.

INTRODUCTION

Many sampling designs for forest biomass inventory require samples of trees that are measured for diameter, among other things, and for which the biomass is estimated from biomass tables normally generated by biomass regression functions. In order to obtain valid forest inventory results, the biomass tables must be representative of the forest area to which they are applied. Basically, the biomass tables have errors, both bias and random, which are due to or are associated with (1) the method of selecting trees, (2) the procedure used to measure or estimate the biomass of these trees, (3) the statistical techniques used in the data analysis and construction of the biomass tables, and (4) the way the tables are applied to a specific inventory design. Furthermore, there is also the basic bias due to the fact that ordinarily the tables are constructed from one and then applied to another forest population.

It is important to know whether a specific method of tree selection leads to samples of trees that are representative of the parent population. And then, it is also important to know whether a specific statistical technique applied to the resulting samples leads to biomass tables of small bias and sufficient precision. It is a combination of sampling and analysis technique that determines whether the inferences made are valid. A sampling method may well lead to representative samples, but if the subsequent statistical procedure of biomass tables construction is not suitably selected, may well lead to invalid inferences. A lengthy discussion of the problems associated with the presently available biomass tables, the soundness of the various sampling and analysis techniques and how they are interdependent are given elsewhere by Cunia (1979a, 1979b).

One way to test whether a sample of trees selected by a specific procedure and analyzed by a given statistical method leads to valid biomass tables is by simulation. Given a forest population of trees for which diameter, height and biomass are known, one can repeatedly select sample trees by a variety of sampling methods, and for each sampling method, one can repeatedly construct biomass tables by a variety of statistical techniques. By applying the resulting biomass tables to the given tree population, and by comparing the estimates based on biomass tables with those of the population

---

[1/]Presented at the "Fifth Annual Southern Forest Biomass Workshop," June 15-17, Charleston, South Carolina, the paper is based on research funded by the Research Foundation of State University of New York, USDA Forest Service and Department of Energy, Grant No. 23-524.

[2/]The authors are respectively Professor of Statistics and Operations Research and Graduate Students at SUNY College of Environmental Science and Forestry, Syracuse, NY 13210.

(which are known) one can draw inferences about the bias, precision and efficiency of specific combinations of sampling method and analysis procedure. One condition for making good simulation studies is to have a large and real-life type of forest population of trees measured for diameter, height and biomass.

To measure large populations of trees for diameter, height and biomass is prohibitively expensive and time consuming. What one can do instead, is to (1) measure large populations of trees for diameter and characteristics other than height and biomass and (2) generate first the height and then the biomass of each tree by Monte Carlo procedures. It is the objective of the present paper to describe such a procedure for generating the total height of trees for which the diameter at breast height, estimated merchantable height and species is known. The procedure for generating the biomass of the trees for which the diameter, total height and species are known will be the objective of a later paper.

The Monte Carlo technique described here calculates the total tree height by a formula of the form

$$y=\hat{y}+q$$

where y is the total height, $\hat{y}=r(d,h)$ is the conditional average of the total height for trees of given diameter d and merchantable height h, and q is a random component representing the variation of the total height y about the regression function $\hat{y}=r(d,h)$.

More specifically, the objective of the paper is to describe how to (1) estimate the regression function $\hat{y}=r(d,h)$, (2) estimate the conditional probability distribution of q and (3) construct a computer simulation program. In addition, we shall also discuss the application of the proposed Monte Carlo procedure to a specific population, the set of approximately 70,000 trees measured on some 3000 sample units (either one-fifth acre sample plots or clusters of 10 point samples) of the New York State inventory system defined as a population of trees.

ESTIMATION OF REGRESSION FUNCTIONS

To estimate the regression function of total height y on diameter d and estimated merchantable height h we have used samples of trees measured for diameter, merchantable and total height from the States of Michigan, New York and West Virginia. We have used a linear regression function of the form

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_5 x_5$$

where y = total height in feet, x_1 = tree diameter at breast height in inches, x_2 = merchantable tree height in feet, $x_3=x_1^2$, $x_4=x_2^2$ and $x_5=x_1x_2$. The merchantable height of the sample trees, measured either before or after felling was ordinarily defined as the height up to a four-inch top. The exceptions were four species from Michigan, namely balsam fir, white spruce and red pine (up to a three and one-half inch top) and trembling aspen (up to a three-inch top).

The method of estimating the regression coefficients was that of least squares and the F-distribution was used to test various null hypotheses. For all species tested, the null hypothesis $\beta_4=\beta_5=0$ was accepted. Except for the red maple from West Virginia and the white ash from New York, the additional hypothesis $\beta_3=0$ in the new linear model $y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3$ was also accepted. Because we expected some values F to be significant even when the null hypothesis is true, we have decided to select the linear model $\hat{y}=\beta_0+\beta_1x_1+\beta_2x_2$ to express the regression function of total height on diameter and merchantable height.

Further regression analysis showed that most of the time either x_1 or x_2 alone was sufficient to adequately describe the regression relationship. That is, after taking into account the effect of x_1, the effect of x_2 was no longer significant, and vice-versa. Because in all cases y was better correlated with x_2 than x_1, we have decided to accept the null hypothesis $\beta_1=0$ for all but three species. More specifically, we have decided to use the model $\hat{y}=\beta_0+\beta_2x_2$ for all but hickory and white oak from West Virginia and white birch from Michigan, where the regression model remained $\hat{y}+\beta_0+\beta_1x_1+\beta_2x_2$. The estimates b_0, b_1 and b_2 of the regression coefficients and $\sqrt{S_{yy|dh}}$ of the conditional standard deviation of the total height (defined as the square root of the sum of squared residuals $(y-\hat{y})^2$ divided by (n-2) or (n-3) as the case may be) as well as the sample size n are all listed by species and state in Table 1.

List of regression functions used and the New York Species to which they were applied

State	Species	List of New York Species
New York	Red Maple	Red and Silver Maple
"	Sugar Maple	Sugar Maple
"	Yellow Birch	Yellow & Sweet Birch
"	Beech	American Beech
"	White Ash	White, Black, Green Ash
"	Basswood	Basswood & Am. Basswood
"	Black Cherry	Blk ch., all other species
W.Virginia	Yel. Poplar	Yel. Poplar, Cucumber Tree
"	White Oak	White and Swamp White Oak
"	Scarlet Oak	Scarlet Oak
"	Chestnut Oak	Chestnut Oak
"	N. Red Oak	Bur, Pin & N. Red Oak; Hickory, Bitternut Hickory and Shagbark Hickory
"	Black Oak	Post and Black Oak
Michigan	Tr. Aspen	Tr. or Bibtooth Aspen
"	Balsam Fir	Bal. Fir; Black, Norway, Blue and Red Spruce
"	Red Pine	Red, Jack, Pitch, E. White and Scots Pine and Hemlock
"	White Spruce	White Spruce

Table 1.--The sample size, the regression coefficients b_1, b_2 and b_3 of the regression function

total height = $b_1 + b_2$ (diameter) + b_3 (merchantable height)

and the conditional standard deviation of a set of 24 samples of trees by state and species.

State	Species	Sample size	Regression number	Regression coefficients b_1	b_2	b_3	Conditional SD $\sqrt{S_{yy\mid dh}}$
New York	Red Maple	44	1	21.425	0	1.03546	6.299
"	Sugar Maple	678	2	33.477	0	.85822	6.715
"	Yellow Birch	15	3	46.935	0	.48425	4.772
"	Beech	29	4	24.479	0	.96307	3.269
"	White Ash	240	5	30.779	0	.87421	6.433
"	Black Cherry	24	6	31.520	0	.78366	3.035
"	Basswood	19	7	39.430	0	.66960	4.553
WVirginia	Red Maple*	17	8	30.221	0	.80913	7.210
"	Hickory*	15	9	40.356	-1.9945	1.07215	2.922
"	Yellow Poplar	17	10	39.572	0	.63497	2.948
"	Black Cherry*	18	11	36.674	0	.69960	6.279
"	White Oak	17	12	33.639	1.5880	.29821	3.027
"	Scarlet Oak	17	13	40.751	0	.53881	2.830
"	Chestnut Oak	18	14	41.585	0	.48834	2.471
"	N. Red Oak	18	15	40.805	0	.62504	4.307
"	Black Oak	18	16	29.915	0	.79821	3.655
Michigan	Tr. Aspen	97	17	9.760	0	1.11161	3.663
"	Balsam Fir	74	18	19.818	0	.76839	3.017
"	Red Maple*	31	19	28.078	0	.80986	3.864
"	Red Oak*	35	20	28.828	0	.75339	2.972
"	Red Pine	59	21	17.977	0	.85621	2.020
"	Sugar Maple*	58	22	37.566	0	.58840	3.936
"	White Birch*	26	23	27.551	1.6532	.40161	4.256
"	White Spruce	59	24	11.924	0	.93523	2.034

*The regression function was not used in the final version of the computer simulation program.

In the population of trees defined for New York State, the species are more numerous than the species listed in Table 1. Furthermore, for some species, Table 1 contained more than one regression function. Then, a decision had to be made to assign one specific regression function to one specific species group. Tabulation shows species assigned to each regression function by the computer simulation program, and the regression functions not used are shown with an asterisk in Table 1.

PROBABILITY DISTRIBUTION OF q

The variable q is defined as the difference between total height y of a specific tree of diameter d and merchantable height h and the average total height, say $\bar{y}_{dh}$ of all population trees of same diameter and merchantable height. This definition implies that the mean of q is zero. The variance of q as well as the overall shape of the probability distribution is most probably a function of tree size (d and h), species, and geographical location (state). Our sample of trees was too small to allow the calculation of the probability distribution of q as a function of tree size, species and state. Instead, we had to content ourselves with the estimation of this probability distribution under the assumptions that (1) the conditional average $\bar{y}_{dh}$ is a linear function of d and h, $\bar{y}_{dh} = \hat{y} = \beta_0 + \beta_1 d + \beta_2 h$, (2) the conditional variance of y for given d and is not a function of d and h, but possibly a function of species and state, (3) the overall shape of the probability distribution of q does not depend on d, h, species and state, and (4) the additional assumptions of the least squares regression analysis (that we do not mention here) are all satisfied. Then, if b_0, b_1 and b_2 are the least squares estimates of the regression coefficients and $S_{yy\mid dh}$ is the corresponding estimate of the conditional variance, the probability distribution of q has been estimated from the behavior of the standardized variable

$e = q/\sqrt{S_{yy\mid dh}}$, where $S_{yy\mid dh}$ values are calculated separately by species and state.

The individual values e that were calculated separately by species and state, were grouped together into classes of width equal to .25, or approximately one-quarter standard deviations. The number of values e falling into each class, expressed as a function of class mid-point, represents a frequency table. Divided by the total number of values e, the absolute frequency

table is transformed into a sample frequency function (or a relative frequency table). Both these tables, as well as the corresponding cumulative frequency tables are shown in Table 2. Note that the relative cumulative frequency table is also known as the sample distribution function of e.

Because of the inherent sampling error, the sample frequency and distribution functions are irregular in shape. They both can be smoothed out by fitting a theoretical probability distribution function, such as, for example, a Normal, Beta or Gamma function. We had preferred using instead a two-stage graphical procedure of smoothing which has the advantage of following more closely the specific peculiarities of the sample probability distribution of e. This graphical procedure can be briefly described as follows.

In the first stage, the sample distribution function was plotted on a graph paper and a smooth approximating curve was drawn by hand. This smooth curve represented the first-stage distribution function. Its values as read directly from the graph at .10 standard deviations intervals were used to estimate a first-stage frequency function.

This new frequency function was then plotted on another graph paper, and its local shape irregularities were eliminated by a second-stage smoothing process, again by hand. Care was taken to continuously have the area under the frequency function equal to one. The values of the newly smoothed curve, again as read directly from the graph, represented the second-stage frequency function. Its values were finally used to calculate the second-stage or final form of the distribution function of e. Before accepting this form as final, we verified that the mean and the variance of the resulting probability distribution were approximately equal to zero and one; in our case they were equal to -.02 and .97 respectively. The graphically smoothed frequency function f(e) and distribution function F(e) are given in Tables 3 and 4, while their graphical representation is shown in Figures 1 and 2.

To generate a random variable q we start by generating a random number r from .0000 to .9999. We continue by finding the corresponding random variable e by solving the equation F(e)=r, more specifically by determining the smallest value F(e) from Table 4 such that F(e)>r. Finally, the random variable q is calculated by the formula $q = e\sqrt{S_{yy|dh}}$, where $S_{yy|dh}$ is the estimate of the variance of q for the given species and state. For example, assume that the random number is r=.7324 and from Table 4 we find that the smallest value F(e) which is larger than .7324 is F(.5)=.7618. Consequently e=.5. Furthermore, if the tree is a red maple, Table 1 gives the value $S_{yy|dh}$=6.299, so $q = e\sqrt{S_{yy|dh}} = (.5)(\sqrt{6.299}) = 1.2549.$

Table 2.--Absolute and relative frequency and cumulative frequency functions of e

class midpoint	frequency absolute	frequency relative	cum. frequency absolute	cum. frequency relative
-3.25	1	.00061	1	.00061
-3.00	2	.00122	3	.00183
-2.75	1	.00061	4	.00243
-2.50	5	.00304	9	.00548
-2.25	5	.00304	14	.00852
-2.00	25	.01522	39	.02374
-1.75	29	.01765	68	.04139
-1.50	54	.03287	122	.07425
-1.25	69	.03774	184	.11199
-1.00	91	.05539	275	.16738
- .75	137	.08338	412	.25076
- .50	182	.11077	594	.36153
- .25	192	.11686	786	.47839
.00	164	.09982	950	.57821
.25	165	.10043	1115	.67864
.50	136	.08278	1251	.76141
.75	106	.06452	1357	.82593
1.00	96	.05843	1453	.88436
1.25	66	.04017	1519	.92453
1.50	35	.02130	1554	.94583
1.75	25	.01522	1579	.96105
2.00	22	.01339	1601	.97444
2.25	11	.00670	1612	.98113
2.50	9	.00548	1621	.98661
2.75	6	.00365	1627	.99026
3.00	4	.00243	1631	.99270
3.25	3	.00183	1634	.99452
3.50	3	.00183	1637	.99635
3.75	3	.00183	1640	.99817
4.00	2	.00122	1642	.99939
4.25	0	.00000	1642	.99939
4.50	0	.00000	1642	.99939
4.75	0	.00000	1642	.99939
5.00	0	.00000	1642	.99939
5.25	1	.00061	1643	1.00000

COMPUTER SIMULATION PROGRAM

To apply the Monte Carlo procedure described here to the population of some 70,000 trees contained in the approximately 3000 sample units (plots or ten point clusters) of the US Forest Service Inventory System of the State of New York, a computer program was written in FORTRAN IV G and run on an IBM 4341 model. The general logic of the program is summarized as the block diagram shown in Figure 3 and the input data expressed as a sequence of tree records were supplied on tape by the Northeastern Experiment Station.

The program starts with the initialization of several counters, switches and constants, and the generation of 1000 random numbers by an IMSL subroutine called GGUBS. The reader having no access to IMSL must write his own subroutine for generating random numbers. The program continues with the reading and storing in the workspace of the data of all tree records from a given sample

Table 3 - The frequency function f(e) as estimated by the two-stage graphical smoothing procedure, where e denotes the midpoint of a class of width equal to .10 standard deviations.

e	f(e)	e	f(e)	e	f(d)	e	f(e)	e	f(e)	e	f(e)
-3.25	.0003	-1.95	.0048	- .65	.0365	.65	.0302	1.95	.0048	3.25	.0007
-3.15	.0004	-1.85	.0062	- .55	.0399	.75	.0289	2.05	.0042	3.35	.0007
-3.05	.0004	-1.75	.0078	- .45	.0427	.85	.0243	2.15	.0037	3.45	.0006
-2.95	.0005	-1.65	.0096	- .35	.0444	.95	.0216	2.25	.0032	3.55	.0006
-2.85	.0005	-1.55	.0114	- .25	.0447	1.05	.0190	2.35	.0027	3.65	.0005
-2.75	.0006	-1.45	.0133	- .15	.0445	1.15	.0163	2.45	.0023	3.75	.0005
-2.65	.0007	-1.35	.0158	- .05	.0440	1.25	.0140	2.55	.0019	3.85	.0004
-2.55	.0010	-1.25	.0178	.05	.0430	1.35	.0120	2.65	.0015	3.95	.0004
-2.45	.0014	-1.15	.0204	.15	.0414	1.45	.0101	2.75	.0013	4.05	.0003
-2.35	.0018	-1.05	.0231	.25	.0394	1.55	.0083	2.85	.0011	4.15	.0003
-2.25	.0022	- .95	.0264	.35	.0376	1.65	.0071	2.95	.0010	4.25	.0002
-2.15	.0030	- .85	.0292	.45	.0354	1.75	.0062	3.05	.0009	4.35	.0001
-2.05	.0038	- .75	.0329	.55	.0330	1.85	.0054	3.15	.0008	4.45	.0001

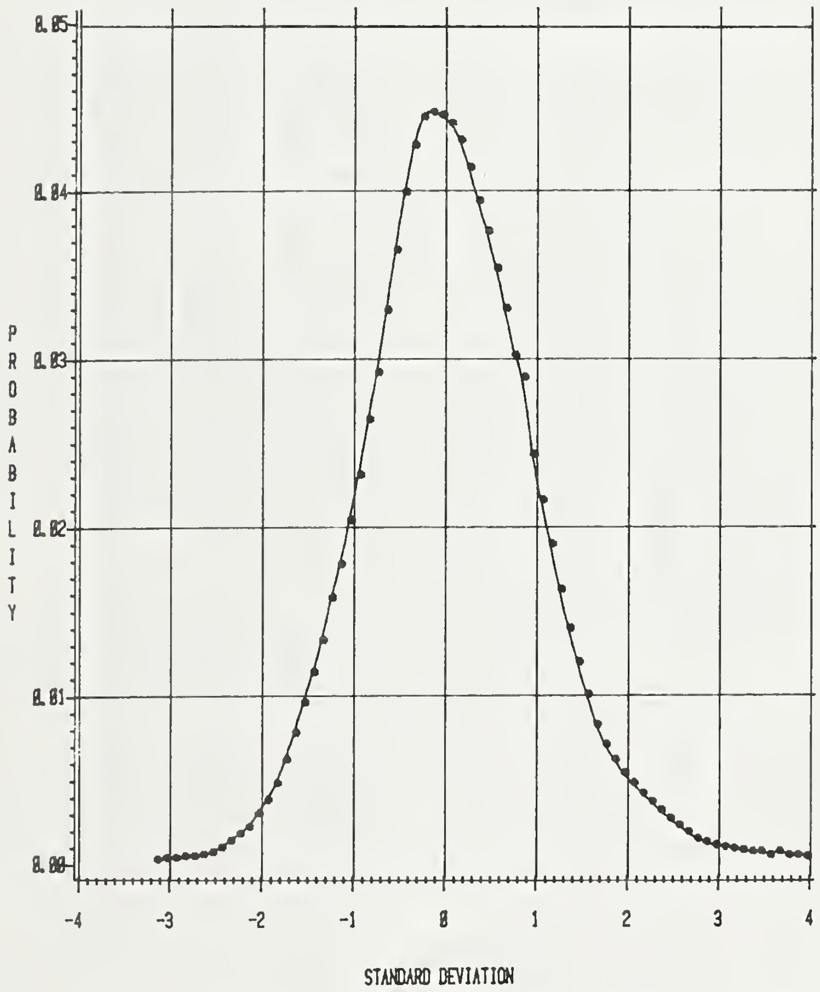

Figure 1 - The frequency function of the random variable e

Table 4 - The distribution function F(e) as estimated by the two-stage graphical smoothing procedure.

e	F(e)	e	F(e)	e	F(e)	e	F(e)	e	F(e)	e	F(e)
-3.2	.0003	-1.9	.0214	- .6	.2718	.7	.7920	2.0	.9700	3.3	.9953
-3.1	.0007	-1.8	.0276	- .5	.3117	.8	.8209	2.1	.9742	3.4	.9960
-3.0	.0011	-1.7	.0354	- .4	.3544	.9	.8452	2.2	.9779	3.5	.9966
-2.9	.0016	-1.6	.0450	- .3	.3988	1.0	.8668	2.3	.9811	3.6	.9972
-2.8	.0021	-1.5	.0564	- .2	.4435	1.1	.8858	2.4	.9838	3.7	.9977
-2.7	.0027	-1.4	.0697	- .1	.4880	1.2	.9021	2.5	.9861	3.8	.9982
-2.6	.0034	-1.3	.0855	.0	.5320	1.3	.9161	2.6	.9880	3.9	.9986
-2.5	.0044	-1.2	.1033	.1	.5750	1.4	.9281	2.7	.9895	4.0	.9990
-2.4	.0058	-1.1	.1237	.2	.6164	1.5	.9382	2.8	.9908	4.1	.9993
-2.3	.0076	-1.0	.1468	.3	.6558	1.6	.9465	2.9	.9919	4.2	.9996
-2.2	.0098	- .9	.1732	.4	.6934	1.7	.9536	3.0	.9929	4.3	.9998
-2.1	.0128	- .8	.2024	.5	.7288	1.8	.9598	3.1	.9938	4.4	.9999
-2.0	.0166	- .7	.2353	.6	.7618	1.9	.9652	3.2	.9946	4.5	1.0000

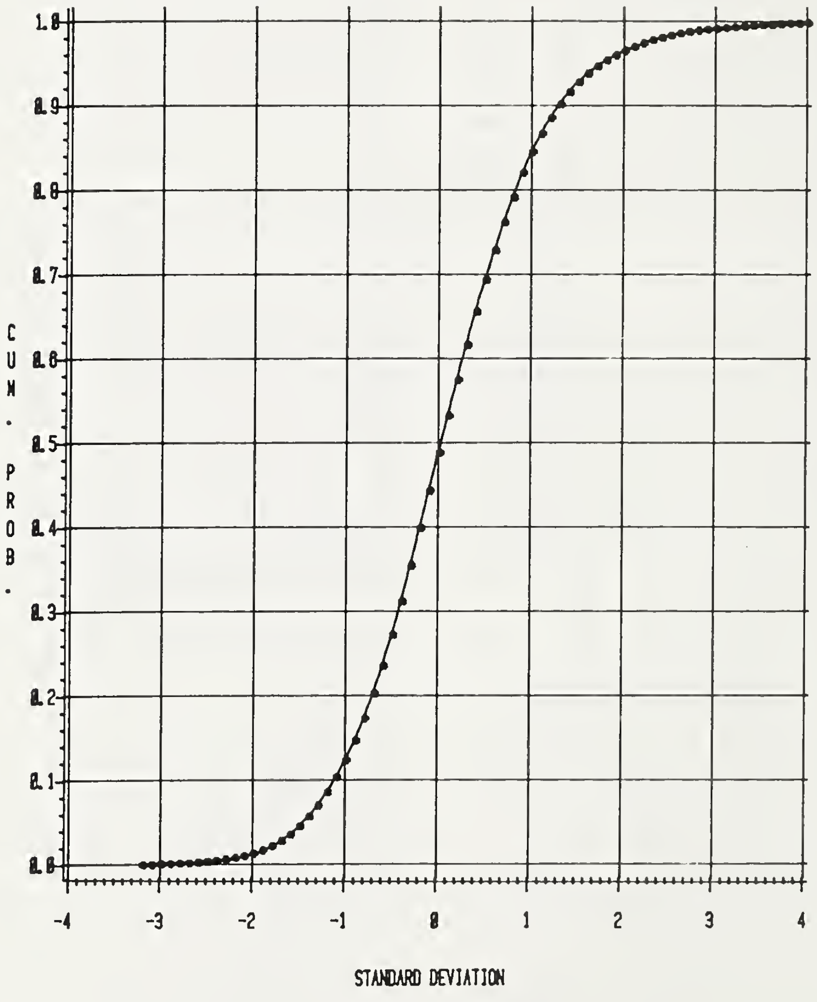

Figure 2. The distribution function of the random variable e

unit. Each tree record is now taken separately and its total height y generated by the following procedure.

If the tree diameter d is equal to zero (the case where the record is that of a sample unit with no trees), the total height y is also made equal to zero. If d is smaller than five and not equal to zero (the unmerchantable tree) the tree record is eliminated from the newly created file. Only when $d \geq 5$ the total height y is generated by the formula $y = b_0 + b_1 d + b_2 h + q$ where (1) the regression coefficients b_0, b_1 and b_2 and the parameter $SD = \sqrt{S_{yy|dh}}$, the conditional standard deviation of y for given d and h are generated by the subroutine COEFF, (2) the random variable e is generated by the subroutine DIST according to the probability distribution of Tables 3 and 4 and (3) the random variable q is calculated as $q=(e)(SD)$. Before using the subroutine DIST, the program verifies that random numbers are still available; if not, subroutine GGUBS is called again to generate a new set of 1000 random numbers.

The total height y so calculated is now tested against the known merchantable height h. If the top length (y-h) is smaller than five feet, the total height y is recalculated by calling again DIST to generate a new random variable e, and subsequently a new value y. If after ten such trials the top length continues to be below five, y is made equal to (h+5) and a special code SUSP is then used to denote this fact.

After the total height of a tree is calculated, a new tree record is constructed. Several fields from the old record are eliminated and two new fields, y and SUSP are added. A new tree is then selected and the whole procedure repeated until all the trees from the current sample unit are exhausted. If all the trees of a given sample unit (plot or point) are smaller than five inches in diameter, an empty record is created to denote this fact.

SUMMARY COMMENTS

We have described a Monte Carlo procedure to generate the total height of a forest tree. The basic approach is to equate total tree height to the sum of an expected height $\hat{y}$ and a random variable q. The expected value $\hat{y}$ is usually, although not necessarily, given by a regression function of total height on known tree and plot variables such as diameter, species, site quality, forest type, age class, etc. The regression function is estimated from a sample of trees measured for all these variables. In addition, this sample of trees provides also an estimate of the conditional probability distribution of q, the difference between the actual and the expected value of the total height.

In our approach, the variables used in the estimation of the expected value of the total height were the tree species, diameter and estimated merchantable height. This is because the population to which the procedure was applied, consisted of trees classified by species for which the diameter was measured and the merchantable height was estimated. The regression function was assumed to be linear and the standard regression analysis applied to samples of trees showed that, after accounting for the linear effect of the merchantable height, the linear effect of the tree diameter is relatively small, if any. In all cases, the quadratic and interaction effects of diameter and merchantable height proved to be insignificantly small. The sample of trees was sufficiently large to allow the estimation of regression functions by species but too small for the estimation by stand variables such as site quality, forest type, etc. or the estimation of the "cluster" effect that makes trees that grow close to each other more similar than trees that grow farther apart.

Note that substituting <u>estimated</u> merchantable height of the sample unit for the <u>measured</u> merchantable height in the regression function does not introduce a basic flaw; neither does the fact that the "cluster" effect is ignored. Because the intent is to construct a real-life type of forest population, having a small bias in the independent variable is not that important; and we expect the "cluster" effect to be included in the diameter and merchantable height values of the tree within the same sample unit.

The sample of trees was also too small to allow us the estimation of the conditional probability distribution of q separately by species, site quality, forest type, etc. What we had to do was to ignore the effect of all variables when estimating the <u>shape</u> of the probability distribution and take into account only the effect of species when estimating the variance. For convenience, the sample probability distribution of the standardized variable e was smoothed by a two-phase graphical procedure, and by using the resulting distribution, define the probability distribution of q by the relation $q = e\sqrt{S_{yy|dh}}$, where $S_{yy|dh}$ defined as a function of species is the estimated conditional variance of y about the regression function.

This approach was finally applied to a real life population defined as the set of some 70,000 trees of merchantable size, measured in the approximately 3000 sample units of the New York State inventory system. Again, the objective of our study was <u>not</u> that of generating the total height of the population trees as they are now; rather, to generate a population of trees that behaves in most respects like real life populations of forest trees. We feel that we have accomplished this in a satisfactory way. Our implicit assumption was that the effects of factors such as site, forest type or tree clustering was to a large extent included in the distribution of tree diameters and merchantable heights as recorded separately in the population by sample units. If there is an effect of the site quality, forest type or

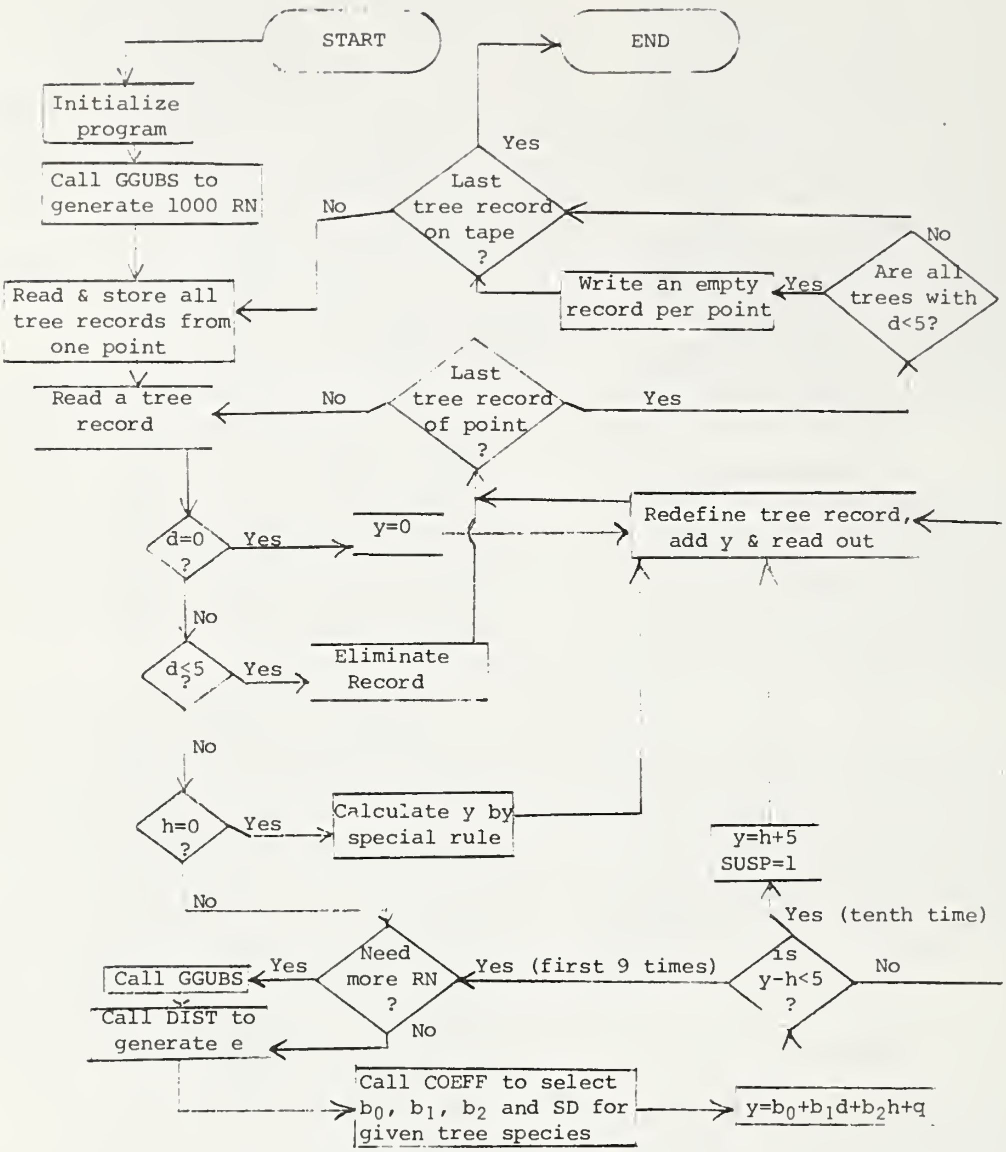

Figure 3 - The logical block diagram of the computer program where d=tree diameter, h=merchantable height, y=total height, b_0, b_1, b_2 are regression coefficients, $SD=\sqrt{S_{yy|dh}}$ = conditional standard deviation of y given d and h, and e and $q=e(SD)$ are random variables.

other micro-environmental factors on the total height of the trees growing within a given sample unit, this effect is expressed implicitly in the joint distribution of the diameters and merchantable heights of the trees as they are distributed within the sample units.

Because the regression functions and the probability distribution of q were estimated from a sample of trees selected from several northeastern states, we feel that the computer program as written can be applied to a variety of forest conditions as they are found in the Northeastern United States. All that is required is to (1) have the diameters and merchantable heights of a population of trees and (2) make some changes in the input and output format of the program. If the merchantable height is missing, one can still apply the approach suggested here by (1) estimaking regression functions of total height on tree diameter (and species) and (2) make changes accordingly to the computer program. The probability distribution of e as calculated here is probably good and does not have to be estimated again.

ACKNOWLEDGEMENTS

Thanks are due to R. Nyland, H. M. Steinhilb and H. W. Wiant for providing us with the sample tree data used in this study.

LITERATURE CITED

Cunia, T.
1979a. On tree biomass tables and regression: some statistical comments. Forest Resource Inventories, Workshop Proceedings, Ed. W. E. Frayer, Colorado State Univ., Fort Collins, CO 80523.

Cunia, T.
1979b. On sampling trees for biomass tables construction: some statistical comments. Forest Resource Inventories, Workshop Proceedings, Ed. W. E. Frayer, Colorado State Univ., Fort Collins, CO 80523.

SESSION 5

FOREST BIOMASS RESEARCH - DISCUSSION OF ON-GOING OR PROPOSED PROJECTS

Moderator: Bryce E. Schlaegel

BIOMASS EQUATIONS FOR YOUNG HARDWOOD SPROUT REGENERATION[1]

Lindsay R. Boring[2] and Wayne T. Swank[3]

Abstract.--Integrated ecosystem studies at Coweeta Hydrologic Laboratory are involved with several aspects of forest biomass and productivity research. This includes regeneration of biomass and vegetation nutrient standing stocks following conventional and whole-tree harvesting. Hardwood sprouts 1-3 years old were sampled in three successive years from an even-aged population on a regenerating clearcut. Linear, linear-weighted, and logarithmic transformed regressions were compared for relative goodness of fit. Log regression equations based upon stem diameter provided the best fits and were selected to predict leaf and wood biomass of 11 species and an "others" category. Significant differences in slopes were found within two groups of species: 1) dogwood, blackgum, sourwood, hickories, mountain laurel, rhododendron, and "others"; 2) chestnut, black locust, red maple, yellow poplar, and oaks. As a result, individual regressions should be used for rhododendron, mountain laurel, hickories and yellow poplar. No significant differences exist among remaining species in each group, and pooled equations may be used for each group. Correction factors for logarithmic bias range from 1-8% of predicted biomass and should be applied to estimates.

BIOMASS RESEARCH AT PINEVILLE, LOUISANA[1]

Richard E. Lohrey[4]

Abstract.--Reliable estimates of the volume growth and yield of artificially regenerated stands of southern pine over a broad range of age, site index, stand density, and cultural practices is a major goal of the Southern Forest Experiment Station at Pineville, LA. Green and dry weight measurements are now being incorporated into long-term field studies to determine biomass as well as volume yields under various silvicultural practices. Equations that estimate multiproduct volumes and biomass of individual trees by component will be developed. These equations and plot data will be used to estimate volume and biomass yields per unit area under various silvicultural treatments.

[1]/Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

[2]/Research Associate, Botany Department and Institute of Ecology, University of Georgia, Athens, GA 30602.

[3]/Plant Ecologist, Coweeta Hydrologic Laboratory, Southeastern Forest Experiment Station, USDA-Forest Service, Otto, NC 28763.

[4]/Research Forester, Southern Forest Experiment Station, Pineville, LA 71360

A BRIEF DISCUSSION OF ETHANOL FROM WOOD AND TVA[1]

Rodger L. Griffith[2]

Abstract.--TVA is charged with providing for the proper use of marginal lands, reforestation, economic development, and national defense. The biomass fuels program contributes to these objectives.

The parts of seven states which form the Tennessee Valley have virtually no petroleum resources, yet over half of the Valley is forested. About 80% of the forest inventory is in hardwoods. Current harvest is only about 33% of annual growth of hardwoods. Even after deducting for areas which should not be harvested for environmental or economic considerations, allowing for a 1.5% buildup in forestry inventory plus an increase in traditional forest products use, preliminary estimates indicate that about 30 million green tons of material is available for energy use annually in the TVA 201-county region. This is primarily surplus material and much is of low quality.

On the other end of the spectrum, liquid fuels--not energy per se--is this country's energy concern. A relatively high Btu liquid fuel for the transportation sector is needed as the stock of petroleum resources diminishes.

How can the available underutilized forest resource base be bridged to meet the end-use energy need? Or stated differently, how can modern technology be employed to convert recently living organic matter (i.e., biomass) to liquid fuel on a much more rapid basis than nature has done over aeons to create petroleum? One project in TVA's Biomass Fuels Program, Ethanol from Hardwood, is focused on developing such technology for industry to commercialize.

With the formation of the biomass fuels program in 1981, TVA initialized laboratory-scale research to convert the surplus hardwood in the 201-county Valley region to ethanol (alcohol) This laboratory work has been complemented by obtaining information on technology and equipment which can be adapted to the production of ethanol from wood, but is currently only being used for other purposes. The process which is being developed relies on use of dilute acid in two stages and temperatures of 145-215°C with retention times dependent on temperature. These conditions convert wood to sugars by reacting wood with dilute sulfuric acid. The sugars are then fermented to produce ethanol. More than two-thirds of the sugars formed from hardwood are the same as sugars which have been fermented to alcohol for centuries. However, there are many wood impurities formed during this process which inhibit fermentation of these sugars. About one-third of the sugars produced have never been fermented to produce alcohol until 1980, and to date this has only been done at the lab scale.

1/Presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

2/Chemical Engineer, National Fertilizer Development Centers, Tennessee Valley Authority, Muscle Shoals, AL 35660.

There is enough hardwood going to waste in the Tennessee Valley to produce about 30-35% as much fuel ethanol as current gasoline consumption in the valley if all of the excess and environmentally harvestable hardwood were converted to ethanol. Development of this technology will help the Valley in overall development of its forests in terms of quality and productivity. As waste scrub timber is harvested, more desirable species can be replanted. The improved forest can be used for greater ethanol production per acre of land and/or other timber requirements which cannot be satisfied with the existing scrub wood. In the long run, the timber resource would be improved.

A COMPREHENSIVE SYSTEM FOR BIOMASS AND VOLUME ESTIMATION OF PLANTATION LOBLOLLY PINE[1/]

Gevan R. Marrs[2/]

Abstract.--A system has been developed which incorporates the capabilities of conventional stem volume, stem taper, and biomass estimation systems, as well as additional features. The system estimates total wood volumes and dry weights for each of seven complete-tree components and can partition each total component estimate above and below any desired height from ground-line, or inside-bark diameter. In addition, the system will partition stem biomass and volume by variable stump heights.

These capabilites are incorporated into an interactive computer program which prints the weight and volume estimates for all portions of the components, and also prints derived property estimates such as wood specific gravity and bark content. Results can also be presented in the form of a scaled schematic representation of each tree.

The system can be applied to existing stands, but its major use will be to evaluate the effects on the complete tree of various stand management practices for hypothetical future stands. This will allow a more complete economic evaluation of the proposed practice.

[1/]Presented at the Fifth Annual Southern Forest Biomass Workshop, Charleston South Carolina, June 15-17, 1983.
[2/]Weyerhauser Corp., Technology Center WTC2H19, Tacoma WA 98477.

SHORT ROTATION WOODY CROPS PROGRAM[1/]

J. L. Trimble[2/]

Abstract.--The Short Rotation Woody Crops Program (SRWCP) is an integrated research program with a single objective: to improve the productivity and economic efficiency of growing woody plants for energy. The SRWCP currently includes 23 research projects across the United States. Eighteen are located at universities, with others at the U.S. Department of Agriculture-Forest Service experiment stations (2) and at private corporations (3). The program is sponsored by the U.S. Department of Energy's Biomass Energy Technology Division and is managed at Oak Ridge National Laboratory.

1. Fertilization and weed control are generally mandatory for ensuring the success of short-rotation woody crops, while irrigation is usually not cost-effective.
2. Improved stand establishment techniques can ensure successful survival (greater than 75%).
3. Intensive management cannot entirely compensate for poor site quality.
4. Immediate productivity gains from selection and management studies can still be expected and longer-term gains from genetic studies are expected in all geographic regions.
5. The economic costs of management practices and cultural treatments that maximize productivity must be evaluated.
6. The economics of short-rotation intensive culture are significantly affected by:

    a. productivity levels,
    b. costs of harvesting and transporting,
    c. risks of crop failure,
    d. lack of developed distribution market for biomass fuels, and
    e. competition for markets (alternative fuels) and for available land (fiber and food crops).

The SRWCP has completed five years of a planned ten-year research program. Research efforts in the next four years will emphasize breeding, propagation, tissue culture, and wood energy qualities. By 1987, the viability of short-rotation intensive culture for the production of energy feedstocks will be evaluated and ready for transfer to the private sector. Future research efforts will focus on achieving the productivity goal of 9 dry tons/acre/year and the cost goal of $2-3.00/million BTUs.

[1/]Presented at the Fifth Annual Southern Forest Biomass Workshop, Charleston, South Carolina, June 15-17, 1983.
[2/]Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

SESSION 6

BIOMASS RESEARCH PRIORITIES

Moderator: Douglas J. Fredrick

WEIGHT EQUATIONS FOR SOUTHERN TREE SPECIES-- WHERE WE ARE AND WHAT IS NEEDED[1/]

Alexander Clark III[2/]

and

Charles E. Thomas[3/]

Abstract.--Southern species sampled for total tree weight equation development are summarized by geographic area and species requiring additional data for equation development are noted. A design for sampling species of minor importance is suggested. The necessity of weight equations by tree component for optimum forestry application is described, and models for predicting weight of these components are presented.

INTRODUCTION

Considerable research on biomass of southern tree species has been conducted by the USDA Forest Service, universities, and forest industry. Thorough reviews of the literature and current research on weight equations for southern species have been conducted by Baldwin (1982), Phillips (1981), McNab and others (1982), and Clark (1982a). These reviews show that weight equations for 43 economically important species, which make up 86 percent of the commercial volume in the South, are available or are being developed but none of these species equations is based on a southwide sample. Some species that are well represented in southern forest types have no regional equations. Some of the available equations are not applicable to forestry because they do not predict weight of the required tree components or are based on independent variables not measured by potential users.

This paper reviews the economically important species which have been sampled for the development of regional weight equations, and suggests species that need additional sampling because of reported regional differences. An efficient design for sampling minor species for equation development is suggested. The paper also discusses tree component weights required for forestry application and suggests models for predicting them.

[1/] Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, SC, June 15-17, 1983.

[2/] Wood Scientist, USDA Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Athens, GA.

[3/] Research Forester, USDA Forest Service, Southern Forest Experiment Station, Forestry Sciences Laboratory, Starkville, MS.

SPECIES WEIGHT EQUATIONS

Hardwoods

Weight equations for hardwood species have been or are being developed for the Gulf and Atlantic-Coastal Plain, Piedmont, and Southern Appalachian Mountain physiographic regions. Trees sampled for equation development include 12 hardwood species (Table 1), which account for 79 percent of the commercial hardwood volume in the Coastal Plain; 13 species, which account for 76 percent of the hardwood volume in the Piedmont--although 4 of these species need additional sampling in the larger diameter classes (Table 2); 15 species, which account for 88 percent of the hardwood volume in the Southern Appalachian Mountains (Table 3); and 12 species, which make up 82 percent of the volume in the South from Alabama to east Texas (Table 4). However, only statewide or local sampling has been conducted in these latter states and no regional equations have been developed.

No statistical comparisons of equations for southern hardwood species have been reported. However, to illustrate the differences in total tree green weight that exists between geographic regions, equations for several important hardwood species were applied to trees with identical d.b.h. and total height (Clark 1982a, 1982b). Results indicate that southern red oak, white oak, and hickory in the Southeast show differences of up to 20 percent or more when compared with results of equations developed for east Texas and Oklahoma. These comparisons also show a difference between the Coastal Plain and West Virginia for red maple. These species differences could be due to chance, to differences among equations, or to actual differences in the physical properties of the species. Equations for other major hardwood species show no within-species differences greater than 15 percent.

Table 1.--Summary of tree species of the Eastern Gulf and Atlantic Coastal Plain sampled for regional weight equations.1/

Species	Locations	Trees	D.b.h. range
	- - - -Number- - -		Inches
Green ash	12	214	1 - 24
Blackgum	13	132	1 - 21
Cottonwood	4	106	1 - 17
Hickory	5	42	1 - 18
Red maple	13	101	1 - 15
Laurel oak	6	27	1 - 14
Live oak	1	37	3 - 21
Water oak	13	176	1 - 20
White oak	6	56	1 - 21
Sweetgum	19	337	1 - 20
Water tupelo	2	150	1 - 20
Yellow-poplar	2	26	5 - 20

1/Includes trees sampled for equation development by Saucier and McNab: Predicted weights and volumes of live oak in northwest Florida, Coop. Study SE-3101-43,Southeastern Forest Experiment Station, Athens, GA; Clark, Phillips, and Frederick: Biomass, nutrient and energy content of southern hardwoods, Coop. Study SE-3101-16, Southeastern Forest Experiment Station, Athens, GA; and Clark, Saucier, McNab: Total tree and tree component weights and volume tables for commercially important hardwood species in Georgia, Coop. Study SE-3101-44, Southeastern Forest Experiment Station, Athens, GA.

Table 2.--Summary of tree species in the Piedmont sampled for regional weight equations.1/

Species	Locations	Trees	D.b.h. range
	- - - -Number- - -		Inches
Green ash2/	5	23	1 - 12
Dogwood2/	2	24	1 - 5
Elm spp.2/	7	28	1 - 12
Hickory spp.2/	10	39	1 - 14
Red maple	9	57	1 - 10
Chestnut oak	2	37	1 - 14
Scrub oak	2	123	1 - 7
Southern red oak	10	75	1 - 18
Scarlet oak	5	28	5 - 18
White oak	2	155	1 - 20
Sweetgum	18	372	1 - 20
Sycamore	3	25	1 - 18
Yellow-poplar	12	142	1 - 20

1/Includes trees sampled for equation development by McNab (1981a); Phillips (1981); Clark, Phillips, and Frederick: Biomass, nutrient and energy content of southern hardwoods, Coop. Study SE-3101-16, Southeastern Forest Experiment Station, Athens, GA; and Clark, Saucier, McNab: Total tree and tree component weight and volume tables for commercially important hardwood species in Georgia, Coop. Study SE-3101-44, Southeastern Forest Experiment Station, Athens, GA.

2/Species requiring additional sampling in larger d.b.h. classes.

Table 3.--Summary of tree species of the Southern Appalachian Mountains sampled for regional weight equations.1/

Species	Locations	Trees	D.b.h. range
	- - - -Number- - -		Inches
White ash	3	52	5 - 22
Basswood	1	18	5 - 16
Sweet birch	1	21	5 - 18
Blackgum	3	36	1 - 18
Dogwood	2	24	1 - 5
Hickory	4	78	1 - 23
Black locust	1	18	5 - 16
Red maple	4	54	1 - 17
Black oak	1	27	5 - 22
Chestnut oak	4	74	1 - 22
Northern red oak	2	71	5 - 24
Sourwood	1	11	1 - 5
Scarlet oak	1	27	5 - 22
White oak	3	46	1 - 22
Yellow-poplar	4	89	1 - 28

1/Includes trees sampled for equation development by Clark and others (1980); Clark and Schroeder (1977); Phillips (1981); and Clark and Schroeder: Multiproduct weight-volume factors and total tree weight and volume of the major southern hardwoods, Study SE-3101-12, Southeastern Forest Experiment Station, Athens, GA.

Within-species differences need to be examined statistically, and appropriate southwide species equations developed where no significant differences occur. The reason for significant differences within species needs to be examined. In some areas of the South, particularly east Texas, eastern Oklahoma, and Arkansas, additional sampling of the major hardwood species may be required since no regionwide sampling has occurred. Red maple, elm, and yellow-poplar have not been sampled in the South but have been sampled in the Southeast for species equations. These species need to be subsampled in the South to determine if equations developed for the Southeast are applicable. Sufficient data are available on major hardwoods in the Southeast to develop species equations for the entire area and by physiographic region except as noted for the Piedmont.

Conifers

Weight equations have also been developed for southern conifers in natural stands. Numerous equations have been generated for the four major southern pines, and are also available for eastern hemlock, pondcypress, Virginia pine, sand pine, and white pine (McNab and others 1982). However, no regional equations for conifer species are available.

As with the hardwoods, there have been no published statistical comparisons of results of equations developed for conifer species at different locations. However, graphs of plotted data for trees at different locations but with identical d.b.h. and total heights show less west-to-east differences for conifers than that reported for hardwoods. However, the four major southern pines

do increase in weight per cubic foot from north to south across their natural ranges (Clark 1982a).

Table 4.--Summary of hardwood species from Alabama to east Texas sampled for weight equations.

Species	Locations	Trees	D.b.h. range	Investigator
		No.	Inches	
Green ash	Mississippi-Delta	--	-	Schlaegel[1/]
Boxelder	Mississippi-Delta	49	1 - 14	Schlaegel 1982
Hickory	Alabama	18	4 - 9	Sirois 1983
	Oklahoma	22	1 - 14	Matney[2/]
Blackjack oak	Oklahoma	15	1 - 12	Matney[2/]
Nuttall oak	Mississippi-Delta	56	3 - 38	Schlaegel & Wilson 1983
Overcup oak	Mississippi-Delta	--	-	Schlaegel[1/]
Southern red oak	Alabama	25	3 - 12	Sirois 1983
	Oklahoma	16	1 - 18	Matney[2/]
	East Texas	33	2 - 21	Lenhart[3/]
White oak	Alabama	14	4 - 9	Sirois 1983
	Oklahoma	32	1 - 18	Matney[2/]
Willow oak	Mississippi-Delta	79	2 - 37	Schlaegel 1981
Sugar-berry	Mississippi-Delta	--	-	Schlaegel[1/]
Sweetgum	Alabama	15	4 - 10	Sirois 1983
	Mississippi	60	1 - 20	Reams and others 1982
	East Texas	30	4 - 12	Lenhart[3/]
Water tupelo	Alabama	30	2 - 20	Glover 1980

1/Schlaegel, Bryce D. Estimated current yields of mixed hardwood stands in the South. Southern Forest Experiment Station, New Orleans, LA, Study SO-1110-34 [in process].

2/Matney, T. G. Biomass equations for selected species in Oklahoma. Weyerhaeuser Co., Hot Springs Forestry Research Center, AR, Unpublished Tech. Rep., 1977.

3/Lenhart, J. D. Estimating the abovestump biomass of loblolly pine, shortleaf pine, southern red oak, and sweetgum trees in mixed pine hardwood stands in east Texas. Stephen F. Austin State University, School of Forestry, Nacogdoches, TX, Unpublished report, 1981.

McNab and others (1982) compared results from five equations developed for loblolly from Texas to Georgia and found only a 3 to 6 percent difference among them. Clark (1982a) compared predictions for slash pine from Georgia, Alabama, and Mississippi and found a maximum of 10 percent difference. The maximum difference among the four major pines was reported for shortleaf sampled in northern Mississippi which differed by 10 to 17 percent compared with samples from Georgia, Texas, and Oklahoma (McNab and others 1982).

For regional resource surveys, southwide, the available equations for major southern pine species appear to be sufficient. However, these equations need to be tested locally before they are used to predict market yields for southern pines. Additional samples of Virginia pine need to be collected in Tennessee, the Carolinas, and Virginia since the only equations available for green weight of total tree and components are based on trees sampled at one location in Georgia (Saucier and Boyd 1982). Stem weight equations for loblolly pine growing in Virginia have been developed (Burkhart and others 1972) but no equations for total tree weight of southern pine based on trees sampled in natural stands in North Carolina or Virginia have been published. Pondcypress also needs to be sampled at additional locations across the South because of reported location-to-location differences (McNab and others 1983). Green and dry weight equations for eastern redcedar and baldcypress based on d.b.h. and total height and height to 4-inch top also need to be developed.

TREE COMPONENTS

In forestry, biomass is expressed in both green and dry weight. Foresters and procurement personnel need the combined green weight of wood and bark for weight scaling of forest products. Plant managers want the green weight of wood and bark separately so they can estimate the energy potential of the bark and convert the weight of the wood into potential units of veneer, lumber, fiber, and pulp. Researchers want the dry weight of wood, bark, and foliage separately so they can evaluate the effects of biomass harvesting on nutrient removals. Wood chemists need the dry weight of wood without bark so they can estimate pulp yields and the energy potential of wood for production of liquid and gas fuels. Thus, when developing biomass equations for forestry application, both green and dry weight equations for the total tree and for the tree components--wood, bark, foliage--are needed.

Researchers have had difficulty summarizing the forestry biomass literature and comparing study results because component parts of the tree were not uniformly defined among researchers. Keays (1971) and other researchers (Young 1964, Clark 1979, Saucier 1979, McNab 1981b) have suggested standard nomenclature for tree components. Listed below is a summary of definitions.

Term	Definition
Complete tree	All component parts of the tree including roots, stump, total stem, branches, foliage, and fruit.
Stump and roots	Stump plus all roots (stump heights dictated by local practice).
Total tree	All components of the tree except stump and roots.
Total stem above stump	Trunk of the tree from stump to tip, minus all foliage, branches, and fruit.
Stem to specified top d.o.b.	Trunk of tree from stump to some specified minimum top--preferably 4-inches (10 cm) d.o.b. or as dictated by local practice.
Saw-log stem	Trunk of tree from stump to 7-inch top for pine or 9-inch for hardwood (d.o.b.) or to where stem quality drops below a grade 3 saw log.
Stem topwood	Portion of total stem above 4-inches (10 cm) d.o.b. or specified top diameter to tip of stem.
Crown	All branches, foliage, and stem topwood.
Branches	All limbs and twigs excluding foliage.
Foliage	All needles or leaves and fruit.

Ideally, green and dry weight equations should be developed for each tree component listed, but this is not economically practical. As a minimum, however, green and dry weight equations for wood and bark and wood alone should be developed for the total tree above stump with and without foliage, total stem, stem to specified top d.o.b., and saw-log stem. With these predicted component weights it is then possible to estimate stem topwood, crown, branches, and foliage by subtraction.

The minimum top diameter at which trees are cut during harvest varies significantly and is dictated by local practice and logging conditions. To meet the needs of all users it is necessary for a researcher to develop a series of independently fitted equations to estimate stem weight to several top diameters (2-, 4-, 7-, 9-inch top). This approach is cumbersome and often leads to what is called crossover (Williams 1982). Crossover occurs when the line for predicted weight to a 7-inch top crosses the predicted weight to a 4-inch top for the same d.b.h. and height tree. This result leads to the illogical conclusion that stems cut at a 7-inch top weigh more than those logged to a 4-inch top.

To avoid this problem, Burkhart (1977) suggests predicting the volume of the total stem and then predict the ratio of the stem volume to the specified top to the total stem volume by using the following nonlinear model:

$$R = 1 + b_1(d^{b_2}/D^{b_3}) \tag{1}$$

Where: R = volume of stem to top diameter/ total stem volume ratio

d = specified top diameter

D = d.b.h.

b_1, b_2, b_3 = regression coefficients

Burkhart's model (1) can lead to illogical ratios if the top diameter is $\geq$ d.b.h. Thus, Van Deusen and others (1981) suggest the following exponential model as an alternative to Burkhart's:

$$R = e^{b_1 X^{b_2}} \tag{2}$$

Where: R = volume of stem to top diameter/ total stem volume ratio

X = specified top diameter/d.b.h.

e = base of natural log

b_1, b_2 = regression coefficients

Models (1) and (2) can be used to estimate stem weight to any specified top by simply substituting weight for volume in the analysis.

Models (1) and (2) were developed for plantation pine and researchers found the combination of the height with d.b.h. did not significantly reduce the sum of squares for their models. Analysis of a large natural pine and hardwood data base shows that the ratio of stem weight to a 4-inch d.o.b. top/total stem weight (Rw) is significantly correlated with total tree heights within 2-inch d.b.h. classes in trees 6-20 inches d.b.h. However, the addition of height in models (1) and (2) did not significantly reduce the sum of squares for the natural pine and hardwood data either. The exponential form of Burkhart's model, model (1), was found to be the best overall ratio model for the natural pine and hardwood data sets analyzed.

$$R = e^{b_1(d^{b_2}/D^{b_3})} \tag{3}$$

Where: R = volume of stem to top diameter/ total stem volume ratio

d = specified top diameter

D = d.b.h.

e = base of natural log

The ratio models developed by Burkhart (1977) and Van Deusen and others (1981) can be used to estimate stem ratios to any specified top diameter when cruising by d.b.h., d.b.h. and total height, or height to 4-inch top since these tree dimensions are good predictors of total stem weight. Sawtimber trees, particularly hardwoods, are cruised by d.b.h. and saw-log height to estimate saw-log stem weight as accurately as possible by using linear equations. Thus, Burkhart and Van Deusen's models are not applicable to trees cruised by d.b.h. and saw-log height. The following nonlinear model is suggested for predicting the ratio of weight to specified top diameter/saw-log stem weight:

$$R_s = e^{b_1 Mh^{b_2}\left(\left(1 - \frac{d^2}{D^2 (0.78)^2}\right)^2\right)^{b_3}} \qquad (4)$$

Where: R_s = weight of stem to top diameter/weight of saw-log stem ratio

Mh = saw-log merchantable height

d = specified top diameter

D = d.b.h. and 0.78D estimates the d.o.b. at the top of the first 16-ft saw log

Model (4) can be used to estimate the weight of the stem in saw-log trees to any specified diameter without crossover, assuming d is less than 0.78D.

By developing equations to predict the total stem using d.b.h. or d.b.h. and total height or height to 4-inch d.o.b. top; saw-log stem using d.b.h. and saw-log merchantable height; and ratio equations using models (3) or (4), researchers can provide users with a series of very versatile and useful equations. These equations will prevent crossover when applying weight equations to large trees.

EQUATION DEVELOPMENT FOR MINOR SPECIES

The USDA Forest Service Forest Inventory and Analysis Units (Survey) in the South and Southeast tally more than 100 individual species during their inventories, but weight equations for many species of minor economic importance are not available. However, weight equations for these minor species are needed for the development of state, regional, and national total-tree biomass statistics such as those published in 1981 for the Nation (Bones and others 1981) and the Southeast (McClure and others 1981). At the present time, biomass equations for 60 percent of the species tallied are not available and are estimated by substituting other species equations.

It would be convenient to have individual equations for each species and physiographic condition but it is necessary for Forest Service and industrial researchers to set priorities and concentrate on the economically important species. Development of weight equations for minor species could be an area of research for a Master-level student. Information available from a related major species could be used to reduce sampling requirements for minor species of interest. Biomass equations are linear or can be transformed into a linear form using a log-log transformation when diameter squared X height (D^2H) is the independent variable. (The use of the log-log transformation can result in a relatively uniform variance.) A low-intensity sampling design could be used to produce practical results for lesser species. Demaerschalk and Kozak (1974) suggest an efficient sampling design for developing linear regression equations when an underlying relationship can be assumed. For the linear case, they suggest limit of range sampling (LORS). For biomass, samples are selected with known D^2H near lower and upper extremes of the D^2H range. From a geometric point of view this makes good sense because only two points are needed to determine the position of a straight line and the accuracy of the resulting line depends on the separation of the independent variable (D^2H) components. They present equations for the means and variances of the sampling distribution of X's and an equation for estimating the number of observations needed to satisfy the precision requirements of the equation being developed.

For minor species needing individual equations, a modification of Demaerschalk and Kozak's simplest selection scheme could be adopted. Using available biomass data for species similar to the species to be sampled, estimate the number of trees needed in the 6-inch and upper-limit diameter class. The size of the trees to be sampled for the upper-limit diameter class should be determined from forest survey data for the species to be sampled. This sampling design would permit not only total tree equation development but would also provide data for development of tree component equations for trees $\geq$ 5-inches d.b.h. In addition, assuming a log-log equation is used, the line could be extrapolated down to 1-inch for sapling-size trees or trees in the 2-inch class could also be sampled.

Since most trees selected for weight analysis are selected in d.b.h. classes rather than D^2H classes, the following formula (Freese 1962) was used to obtain a rough estimate of the sample size required for the upper-limit d.b.h. class.

$$n = \frac{t^2 s^2_{y_p}}{E^2_{y_p}} \qquad (5)$$

Where: n = sample size

t = student's t value for $n_p - 1$ and .05

$s^2_{y_p}$ = estimate of variance of $\bar{Y}$ from previously sampled similar species

$$E_{y_p} = 0.15\left(Y_p - \frac{2\sqrt{s^2_{y_p}}}{\sqrt{n_p}}\right) \qquad (6)$$

p = previous results from similar species

E_{y_p} = lower confidence limit for $E(\bar{Y}_p)$

E_{yp} is a conservative error associated with the upper d.b.h. class which tends to inflate the results produced by (5). Since trees in the 6-inch d.b.h. class are easier and more economical to sample, the sample size for this class could be chosen to equal or exceed the result estimated by (5) for the upper d.b.h. class.

Using previously collected data for 225 sweetgum trees 5- to 20-inches d.b.h., we estimated that 5 trees would be needed in each of two d.b.h. classes to obtain an estimate of total tree weight ($\bar{Y}$) within ± 15 percent 95 percent of the time. To be conservative we said our estimate could be as much as two standard deviations below $\bar{Y}p$. We obtained similar results when using Demaserschalk and Kozak's equation with our previously collected data for sweetgum and other species.

We suggest using LORS only for trees of minor importance. Commercially important species which represent a large portion of the volume require more intensive investigation.

In biomass studies, sampling large trees is much more expensive than sampling small trees. Thus, the design for a large sampling of minor species should take into account differences in cost when determining sampling allocation.

CONCLUSIONS

Weight equations for 43 species, which account for 86 percent of the timber volume on commercial forest land in the South, have been or are being developed. None of these species equations, however, is based on a southwide sample. Existing equations need to be compared statistically, and southwide equations developed when no significant differences exist. The reasons for significant regional differences within a species need to be examined. Existing equations are sufficient for regional resource surveys but need to be tested locally before being used to estimate the market potential of forest products.

Sufficient weight data have been collected on the major hardwood species in the Southeast to develop equations for physiographic regions and for the Southeast area. In the South, however, no regional sampling of hardwoods has occurred, and some species--red maple, elm, yellow-poplar--sampled in the Southeast have not been sampled in the South. These species need to be sampled in the South to determine if equations developed in the Southeast are applicable. Conifer species requiring additional sampling in the South and Southeast are Virginia pine, pondcypress, baldcypress, and eastern redcedar.

Equations do not exist for a large number of low-value species, and they are now estimated by substituting equations for similar species. When equations for minor species are developed, data collected on major species should be used to develop an efficient, inexpensive sampling design for collecting weight data for the minor species. To make weight equations more versatile and prevent illogical stem estimates, variable top-ratio equations should be developed.

LITERATURE CITED

Baldwin, V. C.
1982. A summary of published southern pine plantation tree biomass studies. In: Baldwin, V. C., Jr.; Lohrey, R. E., eds. Proceedings of 1982 southern forest biomass working group workshop; 1982 June 16-18; Alexandria, LA; 33-45. Available from: Louisiana State University, Baton Rouge, LA.

Bones, J. T.; Cost, N. D.; Howard, J. O. [and others]
1981. Tree biomass--a state-of-the-art compilation. Gen. Tech. Rep. WO-33. Washington, DC: U.S. Department of Agriculture, Forest Service; 34 p.

Burkhart, H. E.
1977. Cubic-foot volume of loblolly pine to any merchantable top limit. South. J. Appl. For. 1(2):7-9.

Burkhart, H. E.; Parker, R. C.; Oderwald, R. C.
1972. Yields for natural stands of loblolly pine. Res. Pub. FWS-2-72. Blacksburg, VA: Virginia Polytechnic Institute and State University; 63 p.

Clark, Alexander, III.
1979. Suggested procedures for measuring tree biomass and reporting tree prediction equations. In: Frayer, W. E., ed. Forest resource inventories: proceedings of the workshop; 1979 July 23-26; Fort Collins, CO; Vol. II; 615-628. Available from: Colorado State University, Fort Collins, CO.

Clark, Alexander, III.
1982a. Predicting biomass production in the South. In: Hotvedt, James D.; Jackson, Ben D., eds. Proceedings of the 31st annual forestry symposium: predicting growth and yield in the midsouth; 1982 April 13-14; Baton Rouge, LA: Louisiana State Univ.; 119-139.

Clark, Alexander, III.
1982b. Status of biomass estimation of southern hardwood species and stands. In: Baldwin, V. C., Jr.; Lohrey, R. E., eds. Proceedings of 1982 southern forest biomass working group workshop; 1982 June 16-18; Alexandria, LA; 3-15. Available from: Louisiana State University, Baton Rouge, LA.

Clark, Alexander,III; Phillips, Douglas R.; Schroeder, James G.
1980. Predicted weight and volumes of northern red oak trees in western North Carolina. Res. Pap. SE-209. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 22 p.

Clark, Alexander, III; Schroeder, James G.
1977. Biomass of yellow-poplar in natural stands in western North Carolina. Res. Pap. SE-165. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 41 p.

Demaerschalk, J. P.; Kozak, A.
1974. Suggestions and criteria for more effective regression sampling. Can. J. For. Res. (4): 341-348.

Freese, Frank.
1962. Elementary forest sampling. Agric. Handb. No. 232. Washington, DC: U.S. Department of Agriculture, Forest Service; 91 p.

Glover, G.
1980. Biomass tables for southern forest tree species. (Unpublished.) Coop. Agree. 19-316. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Keays, J. L.
1971. Complete tree utilization: an analysis of the literature. Inf. Rep. VP-C-69, 70, 71, 77, 79. Canada, Vancouver, B.C.:Western Forest Products Laboratory.

McClure, Joe P.; Saucier, Joseph R.; Biesterfeldt, R. C.
1981. Biomass in southeastern forests. Res. Pap. SE-227. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 38 p.

McNab, W. Henry
1981a. Total tree and firewood weights and volumes of scrub oaks in the Georgia sandhills. Ga. For. Res. Pap. 22. Macon, GA: Georgia Forestry Commission; 15 p.

McNab, W. Henry
1981b. What and how to report biomass results--a Forest Service perspective. In: Gresham, Charles A., ed. Proceedings of 1981 southern forest biomass workshop; 1981 June 11-12; Georgetown, SC; 124-129. Available from: Clemson University, Clemson, SC.

McNab, W. Henry; Clark, Alexander, III; Thomas, Charles E.
1982. Status of biomass estimation of southern conifers in natural stands. In: Baldwin, V. C., Jr.; Lohrey, R. E., eds. Proceedings of 1982 southern forest biomass working group workshop; 1982 June 16-18; Alexandria, LA; 25-32. Available from: Louisiana State University, Baton Rouge, LA.

McNab, W. Henry; Saucier, J. R.; Phillips, D. R.
1983. Green weight and wood and bark properties of pondcypress in central Florida. In: Daniels, R. F., ed. Proceedings of 1983 southern forest biomass working group workshop; 1983 June 15-17; Charleston, SC. Available from: Southeastern Forest Experiment Station, Asheville, NC.

Phillips, Douglas R.
1981. Predicted total-tree biomass of understory hardwoods. Res. Pap. SE-223. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 22 p.

Reams, Gregory A.; Sullivan, Alfred D.; Matney, Thomas G.; Stevens, Robert R.
1982. Estimating above-ground biomass of slash pine and sweetgum. Tech. Bull. 110. Mississippi State, MS: Mississippi State University; 11 p.

Saucier, J. R.
1979. Estimation of biomass production and removal. In: Proceedings: impact of intensive harvesting on forest nutrient cycling; 1979 August 13-16; Syracuse, NY; 172-189. Available from: Northeastern Forest Experiment Station, Broomall, PA.

Saucier, J. R.; Boyd, J. A.
1982. Aboveground biomass of Virginia pine in north Georgia. Res. Pap. SE-232. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 32 p.

Schlaegel, Bryce E.
1981. Willow oak volume and weight tables for the Mississippi Delta. Res. Pap. SO-173. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 14 p.

Schlaegel, Bryce E.
1982. Boxelder (Acer negundo L.) biomass component regression analysis for the Mississippi Delta. For. Sci. 28(2): 355-358.

Schlaegel, Bryce E.; Wilson, Regan B.
1983. Nuttall oak volume and weight tables. Res. Pap. SO-186. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 14 p.

Sirois, Donald L.
1983. Biomass of four hardwoods from lower Piedmont pine-hardwood mixed stands in Alabama. Res. Pap. SO-46. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 18 p.

Van Deusen, P. C.; Sullivan, A. D.; Matney, T. G.
1981. A prediction system for cubic-foot volume of loblolly pine applicable through much of its range. South. J. Appl. For 5(4): 186-189.

Williams, James G.
1982. Modeling problems in predicting total-tree component biomass. In: Baldwin, V. C., Jr.; Lohrey, R. E., eds. Proceedings of 1982 southern forest biomass working group workshop; 1982 June 16-18; Alexandria, LA; 111-115. Available from: Louisiana State University, Baton Rouge, LA.

Young, H. E.
1964. The complete tree concept--a challenge and an opportunity. In: Proceedings of Society of American Foresters meeting. 1964 September 27-October 1; Denver, CO; 231-233.

BIOMASS DYNAMICS - INTEGRATING BIOMASS WITH GROWTH AND YIELD RESEARCH[1]

Richard F. Daniels[2]

Abstract.--Common goals in biomass estimation studies and traditional growth and yield research are explored. In general, biomass estimation has not been pursued by the growth and yield research community, and major growth and yield studies in the South have not considered biomass as a primary objective. The recent emergence of individual tree biomass and component weight information for many species allows biomass to be incorporated into a number of existing growth and yield projection methods. The result will be practical estimates of biomass and component breakdown at the stand level with associated mechanisms for projecting future biomass yield and dynamics. New generations of growth and yield models may be improved by considering total biomass as a primary objective. Biologically based boundary conditions for productivity estimates can be established on the basis of total biomass, and the breakdown and dynamics of the total resource may be more predictable once these boundary conditions are established.

The self-thinning or "-3/2 power" law is cited as an example of the use of total biomass in defining basic yield principles. Growth trajectory, distribution of biomass, mixed species considerations, and concepts for yield improvement are discussed in this context.

The recent interest in quantifying biomass may be considered, in the simplest sense, just an extension of traditional growth and yield estimation. Weight is just another unit to estimate, along with board foot volume, cubic foot volume, and cords. However, interest in biomass has arisen from the genuine and pure scientific objectives of comparative ecosystem productivity and the practical and real information needs brought about by energy and new resource utilization potentials. These new interests have been met by the researchers and organizations needing the information, and not, in general, by the established growth and yield research community. The result is a great diversity of individual talents, as we see assembled at this workshop. This bringing together of diverse backgrounds has resulted in very positive contributions and holds great potential for the future.

The objectives of this paper are to identify common goals in biomass estimation and growth and yield research; discuss the ways in which biomass research results can be incorporated into existing and emerging growth and yield methodologies to help improve the utility of this information; and to briefly discuss how consideration of biomass dynamics can improve traditional growth and yield modeling in meeting future information needs.

Background

Forest biomass is a dynamic resource. The distribution of biomass within a tree or stand of trees is constantly changing. Total biomass may approach a constant for any site. This concept has led to a static view of biomass. The destructive sampling required in biomass work further adds to our static view because trees are examined at just one point in their development. Finally, the urgent information need to quantify what is out there also contributes to the short-term view.

The major emphasis in biomass work has been in the construction of biomass tables and equations which apply to individual trees. This work is also critical to development of stand level biomass estimates. As noted by Clark and Thomas (1983), there are still species to be quantified, other species for which information

[1]Presented at the Fifth Annual Southern Forest Biomass Workshop, June 15-17, 1983, Charleston, SC.

[2]Project Leader - Forest Biometry, Westvaco Corporation, Forest Science Laboratory, Summerville, SC 29483.

needs to be refined, and still more improvements to be made in modeling and standardization. But, considerable progress has been made in the development of tree biomass information.

Growth and yield models deal primarily with stand level, area-based estimates of one or more products, and the growth, structure, and dynamics of stands. These objectives are very similar to the objectives of very basic primary productivity studies. However, traditional growth and yield studies have generally considered only the merchantable portion of the stand - just a piece of the total picture. Green weight estimates have been added and merchantability limits relaxed only as these values were required for operational decision making. Biomass equations were not available in early yield studies, and there was little interest in quantifying products of limited use or value operationally. Major growth and yield studies have not considered total biomass as a primary objective. Very few have incorporated published biomass equations into yield estimates and projections.

The recent development of tree weight equations for many species has made it possible to construct biomass growth and yield systems. A look at the development of growth and yield methodology will show what can be done right now to incorporate biomass into existing yield estimation and projection methods.

Modern growth and yield modeling got its start in the late 1930's when MacKinney and Chaiken (1939) literally "cranked out" the first multiple regression equation for variable density yield estimation. Yield was expressed as a linear model involving age, site index, and stand density. Similar methods were used to develop stand level yield and growth equations through the early 60's when the differential/integral relationship between growth and yield was recognized and modeled (Clutter, 1963, Buckman, 1962). This application of very basic biomathematics kicked off a new era of improved growth and yield models culminating in the 1970's with an explosion of new methodology made possible through the computer and the ability to implement new and more sophisticated techniques.

Of these new methods, diameter distribution-based models and individual tree-based models have shown considerable utility. Diameter distribution models involve the use of a probability distribution function to describe the distribution of diameters in the stand. Distribution parameters are usually predicted as a function of stand level conditions (age, site index and density). Heights are predicted for each diameter class. Volume (or weight) is estimated for each class by substituting diameter and height into an appropriate volume (or weight) equation and multiplying by the expected frequency from the diameter distribution. Considerable detail on stand structure can be provided using this method. Growth projections are generally made either by projecting the basic stand-level predictor variables or by projecting parameter values directly.

Published models have differed mostly in the probability density function used to describe diameters. Early studies used the beta distribution (e.g. Bennett and Clutter 1968; Beck and Della-Bianca 1970). More recently the Weibull distribution has been adopted (e.g. Dell et al. 1979, Smalley and Bailey 1974). Johnson's S_{bb} distribution has been used to describe the bivariate joint height-diameter distributions of loblolly pine stands (Hafley et al. 1982). Most studies have been in even-aged pine stands, although diameter distribution techniques have also been applied to mixed species in uneven-aged hardwood stands (Stiff 1980).

Individual tree models are based on simulating the growth of individual trees in a stand. Models which include the effects of competition from neighboring trees in estimating tree growth have been called distance dependent individual tree models because the location of each tree is required. These models are the most complex and, in many ways, the most flexible for describing effects of forest management activities. PTAEDA, the loblolly pine model of Daniels and Burkhart (1975) is the only individual tree distance dependent model that has been developed in the South. Ek and Monserud (1974) demonstrated the utility of this approach in mixed hardwoods. More recently, a distance independent model, STEMS, has been developed which projects almost any conceivable mixed or pure stand type in the lake states (Belcher, et al. 1983). Individual tree models can be used for projecting almost any stand product or component by substituting simulated diameter and height values into an appropriate tree volume or weight equation.

Using Current Growth and Yield Methods for Biomass

A wide variety of growth and yield modeling alternatives have been developed which are well suited to a variety of needs. The choice of any method should be dependent on the level of detail, flexibility, and efficiency required (Daniels, Burkhart, and Strub 1979). Stand level biomass growth and yield models may now be devel-

oped by analyzing data from past or current yield studies using newly available biomass and component weight equations. Stand level models are a logical choice for total biomass prediction because of the stability of this total productivity measure. However, difficulties arise in estimating the stand component breakdown of total biomass yield. Further, published models cannot be converted directly to biomass without reanalyzing the original plot data. Last year Brenneman and Daniels (1982) presented experiences in working up traditional area yield plots for constructing stand level biomass yield equations. Yield equations were then constructed for: (1) sawtimber, in board feet, cords, cubic feet, green weight, (2) pulpwood in cubic feet, cords and green weight, (3) topwood in cubic feet, cords and green weight, and (4) twigs and branchwood. The problem is one of constructing a system of 12 or more yield equations which are logically related and consistent.

Most applications will require the component breakdown of total stand yield. In this case, it may make more sense to use a diameter distribution approach. Here the diameter distribution is determined and used to expand estimates from any desired volume or weight equation for each size class. Unit area yield estimates are made by summing over the size classes of interest. The role of the tree level weight equations is especially clear here. Care must be taken, however, since most distribution models will not ensure that estimates of total yield, over all size classes, are logically constrained, as they are when estimated directly from stand level equations. Some more recent studies (Hyink 1980 and others) have "recovered" distribution parameters from stand level equations which can be logically constrained.

Daniels (1981) presented a framework which unifies stand level, distribution, and individual tree modeling approaches using tree volume or weight equations and a common core of growth and survival functions. This approach may allow more flexibility in substituting appropriate tree volume and weight equations for stand level estimates.

Future Directions and Challenges

We are on the verge of some very exciting times in all branches of forestry. In biometrics, we can no longer wait for the results of long-term data to begin modeling results of new practices. Land managers need decision information. We must be looking at biological processes and causal mechanisms rather than just fitting outcomes. The lag between new technology in forest management and new information for decision making must be shortened.

In biomass estimation *per se*, individual tree equations will continue to be a key to future modeling efforts and flexible approaches such as ratio models for component estimates are needed (Clark and Thomas 1983). Also needed are the best, broad-based equations which can be developed. This means pooling tree data, maybe creation of a central biomass data bank, and meeting head on the questions of regional variability, consistency, and changes in tree characteristics over time. We know variation exists. What are the structural, biophysical, and biochemical reasons?

We are currently involved in major efforts to model response to intensive culture and identify the biological potential of our stands at Westvaco. In this context, total biomass defines both site and utilization potential. It allows us to look at the entire picture. A jigsaw or picture puzzle is easier to solve if the border and corner pieces are identified - particularly the corners. A major problem in current growth and yield methodology arises directly from its narrow view of describing the merchantable forest. Patterns in the middle are being found, but not the corner pieces that define the limits -the biologically-based border conditions. Farnum *et al.* (1983) demonstrated Weyerhaeuser's use of theoretical models of potential productivity to help define target yields. Such analyses help define the key elements of yield improvement.

An example may help to illustrate the potential of considering biomass in theoretically based growth and yield models. The self-thinning line or the "-3/2 power" law (see Aikman and Watkinson 1980, Drew and Flewelling 1977) has been observed in even-aged forest plantations and field crops. Stands start out at low intraspecific competition levels and approach a maximum density line. At that point, increases in size come at the expense of density. The slope of the line is remarkably similar for many species. The phenomenon is observed for most any size measure, but is most general if total weight is used. This is a basic biological boundary condition for stand growth. It defines total biomass potential. A time scale added to the trajectory provides a theoretical growth and yield relationship. By describing the size distribution about the average, a very flexible model may result which could be used to partition biomass components for improved operational predictions. Some interesting questions arise. If the slope is fixed, can the line at least be raised perhaps through genetic or cultural improvements? Can we generalize the model to mixed stands? What species parameters need to be considered? Can energy and nutrient equations be

be considered in this framework?

Conclusions

Integration of knowledge, talents, and data may hold the key to quantum breakthroughs, not just in meeting information needs, but real scientific gains. Emphasis on total biomass and its distribution and associated nutrient and energy values will surpass strict interest in merchantable products. Greater interest in biochemical and biophysical causal agents in forest dynamics will lead to better biomathematical descriptions of growth and structure. The results will be dependent on a cycle of well-founded theory and hard data.

LITERATURE CITED

Aikman, D. P. and A. R. Watkinson. 1980. A model for growth and self-thinning in even-aged monocultures of plants. Ann. Bot. 45:419-427.

Beck, D. E. and L. Della-Bianca. 1970. Yields of unthinned yellow poplar. USDA Forest Service, Res. Pap. SE-58. 20pp.

Bennett, F. A. and J. L. Clutter. 1968. Multiple-product yield estimates for unthinned slash pine plantations--pulpwood, sawtimber, gum. USDA Forest Service, Research Paper SE-35, 21p.

Belcher, D. W., M. R. Holdaway, and G. J. Brand. 1983. A description of STEMS: the stand and tree evaluation and modeling system. USDA Forest Service. Gen. Tech. Rep. NC-79. 18p.

Brenneman, B. B. and R. F. Daniels. 1982. A case study with alternatives for calculating biomass yield. In: Proceedings of the 1982 Southern Forest Biomass Workshop. (Eds. V. C. Baldwin and R. E. Lohrey). p. 105-110. USDA Forest Service. Southern Forest Experiment Station, Alexandria, LA.

Buckman, R. E. 1962. Growth and yield of red pine in Minnesota. USDA Tech. Bull. 1272, 50p.

Clark, A., III and C. E. Thomas. 1983. Weight equations for southern tree species--where we are and what is needed. In: Proceedings of the 1983 Southern Forest Biomass Workshop (Eds. R. F. Daniels and P. H. Dunham). Charleston, SC. June 15-17, 1983 (in press).

Clutter, J. L. 1963. Compatible growth and yield models for loblolly pine. Forest Sci. 9:354-371.

Daniels, R. F. 1981. An integrated system of stand models for loblolly pine. Ph. D. Dissertation. Va. Polytech. Inst. and State Univ., 105p.

Daniels, R. F. and H. E. Burkhart. 1975. Simulation of individual tree growth and stand development in managed loblolly pine plantations. Div. of Forestry and Wildlife Resources, Va. Polytech. Inst. and State Univ., FWS-5-75, 69p.

Daniels, R. F., H. E. Burkhart, and M. R. Strub. 1979a. Yield estimates for loblolly pine plantations. J. Forestry. 79:581-583, 586.

Dell, T. R., D. P. Feduccia, T. E. Campbell, W. F. Mann, Jr., and B. H. Polmer. 1979. Yields of unthinned slash pine plantations on cutover sites in the West Gulf region. USDA Forest Service, Research Paper SO-147. 84p.

Drew, T. J. and J. W. Flewelling. 1977. Some recent Japanese theories of yield-density relationships and their application to Monterey pine plantations. Forest Sci. 25:518-532

Ek, A. R. and R. A. Monserud. 1974. FOREST: A computer model for simulating the growth and reproduction of mixed species forest stands. School of Natural Resources, University of Wisconsin, Res. Rep. R2635, 13p.

Farnum, P., R. Timmis, and J. L. Kulp. 1983. Biotechnology of Forest Yield. Science 219:694-702.

Hafley, W. L., W. D. Smith, and M. A. Buford. 1982. A new yield prediction model for unthinned loblolly pine plantations. Tech. Rep 1. Bioeconomic Modeling Project, S. For. Res. Cen., N.C. State Univ., Raleigh, NC. 65p.

Hyink, D. M. 1980. Diameter distribution approaches to growth and yield modeling. Proc. Workshop on Forecasting Forest Stand Dynamics. Lakehead Univ., Thunder Bay, Ontario. June 24-25, 1980.

MacKinney, A. L. and L. E. Chaiken. 1939. Volume, yield, and growth of loblolly pine in the Mid-Atlantic Coastal Region. USDA Forest Service, Technical Note No. 33, 30p.

Smalley, G. W. and R. L. Bailey. 1974a. Yield tables and stand structure for loblolly pine plantations in Tennessee, Alabama, and Geor-

highlands. USDA Forest Service, Research Paper SO-96, 81p.

Stiff, C. T. 1980. Modeling the growth dynamics of natural mixed-species Appalachian hardwoods. Ph.D. Dissertation, Va. Polytech. Inst. and State Univ., Blacksburg, VA.

FUTURE OPPORTUNITIES FOR BIOMASS UTILIZATION[1/]

Clifford E. Henry[2/]

Abstract.--Predicting future uses of biomass can be accomplished by evaluating existing trends. Opportunities will be in (1) the production of energy by direct combustion or conversion, (2) the extraction or conversion to chemicals, and (3) the development of the reconstituted board and panel industry and associated markets.

RELATIVENESS OF THE FUTURE

The concept of the future is one which is relative at any one point in time or space. Common activities that we are accustomed to in the United States are sometimes far in advance of the current state in some developing countries. For example, while more than one-third of the world's population depends on fuelwood for heating and cooking (Mnzava 1981), the southern pulp and paper industry is utilizing biomass in the production of steam for industrial purposes. On the other hand, even though the concept of recycling wood is a reality in parts of Europe, it exists only as a futuristic idea in our minds today. This paper will present some future opportunities based on existing trends in the southern United States. As a result, some of you may already be "cashing in" on some of these opportunities while to others they may seem as a "pine in the sky."

FUTURE OPPORTUNITIES

The opportunities for biomass utilization fall into the following categories:

1. Energy
2. Chemical conversions
3. Reconstituted board and panel production

ENERGY FROM BIOMASS

At the end of the last decade we were faced with an oil crisis which forced us to look at our only renewable resource--the forests-- to solve our energy problems. Some enthusiastic individuals lost sight of the fact that using harvest residues and salvageable dead trees for energy could only account for three to five percent of our nation's energy needs (Curtis 1978). Energy plantations (Sizego et al 1972) were proposed to be the answer to this dilemma. This led to a host of research projects from species selection, genetics research, silvicultural systems and mensuration (Frederick et al 1978). The temporary halt to the rise in oil prices and the subsequent reduction in interest in biomass has given us an opportunity to complete and evaluate these projects.

The pulp and paper industry is responsible for 3% of the nation's total energy consumption. We, however, have responded to the call for conservation and self-sufficiency by utilizing bark and wood residues and black liquors for internal energy production (Inman et al 1978). My hypothesis is that the forest industry will continue to be the main users of the forest for the production of energy. The supply of energy to other sectors will depend on the timing of the depletion of fossil fuel reserves and the development of alternative forms of energy such as solar, geothermal, hydro or nuclear. If these two occurrences do not coincide, then our forests will be called into action to meet some of our nation's energy requirements.

There are two avenues for increasing the utilization of biomass in energy production. These are (1) increasing the combustion efficiencies of industrial boilers, and (2) converting biomass into liquid or gaseous forms.

Combustion Efficiency

The direct combustion of wood produces lower combustion efficiencies when compared to coal or natural gas. It however is still the most efficient mechanism to convert biomass into energy. The opportunity exists to develop more efficient boilers. Heat which is now being lost to the

1/Paper presented at Southern Forest Biomass Working Group Workshop, Charleston, South Carolina, June 15-17, 1983.

2/Lands and Timber Research Manager, The Buckeye Cellulose Corporation, Route 3 Box 260, Perry, Florida 32347.

atmosphere could be used to (1) reduce the moisture content of the incoming fuel, (2) heat combustion air, or (3) preheat the incoming water before it gets to the boilers.

The cogeneration of steam and electricity would allow for a high quality energy product (electricity) to be produced and transported. This is presently being practiced in Europe. In most cases, a manufacturing facility produces steam for its internal use and sells excess electricity to a utility company. The use of biomass by the forest industry gives us a competitive edge over wood fired generating stations. The raw material is readily available and the by-product gives a mill extra flexibility in producing a versatile product such as electricity.

Converting Biomass into a Liquid or Gaseous Form

One of the advantages of woody biomass is that its energy is stored in a concentrated form. It can be stored on the stump, and in some cases harvested throughout the year. It is bulkier than fossil fuels and part of the combustion inefficiency mentioned above lies in its high moisture content. Converting biomass into a liquid or gas provides cleaner combustion and reduced transportation cost.

One of the established ways of converting biomass is through gasification. This is the thermal decomposition of wood or coal with a limited supply of air or oxygen. The end product is a low or medium BTU calorific gas. This technology is not new. Wood fired gasifiers produced fuel for vehicles in Europe and China during the second World War. One of the advantages of gasification is the ease and low capital investment required to convert boilers presently using natural gas or oil. Additionally, it can be used in situations where clean combustion is required, e.g. lime kilns.

The conversion of biomass to liquid fuels received a lot of attention in the past. Basically it was thought of as a replacement or supplement to gasoline. The two most mentioned fluids are (1) methanol, which is produced by gasification, and (2) ethanol, produced by hydrolysis and fermentation. Production of these liquid fuels have been successfully accomplished using agricultural products. Gasohol, a mixture of gasoline and ethanol, is sold in some gasoline stations in the United States. The most aggressive fossil fuel supplement using ethanol is taking place in Brazil. The challenge ahead is to reduce the cost and improve the efficiency of these conversion systems when using woody biomass. One possible approach will be in the breeding or selection of microbes involved in the breakdown of cellulose or lignin.

CHEMICALS FROM BIOMASS

The production of chemicals from forest biomass is the second area that there will be new opportunities. Various chemicals can be extracted from the foliage or bark which is now being burned or left on site after harvesting. Additionally, woody biomass will also play a part in replacing chemical feedstocks derived from fossil fuel which are used by the chemical industry to produce synthetic fibers and plastics.

Chemical Extractives

It has been proposed that extracting chemicals prior to fiber or fuel production would become a prime factor for survival of the pulp and paper industry (Durso 1975). This industry has demonstrated its ability to produce extractives such as turpentine and tall oil as by-products of the pulping process. There is a possibility of increasing the production of these oleoresins by applying the herbicide paraquat to pine plantations (Blomqvist 1978). Adequate steps will be required to prevent loss of volume growth to insect or disease in the treated plantations.

Polyflavonoids are present in southern pine bark and can be a source of valuable phenolic polymers. These chemicals are important as wood adhesives for the production of reconstituted wood such as flakeboard for external use (Hemingway 1978). Thus biomass could be the source for both fiber and adhesives for these new forest products.

The extraction of essential oils, chlorophyll-carotene paste, sodium chlorophyll and provitamin pastes from coniferous foliage has been done in the Soviet Union on a commercial basis (Watts 1978). With whole tree harvesting, pine foliage can be processed at a mill for these extractable chemicals.

Chemical Feed Stocks

Approximately 4.5% of our hydrocarbon consumption is used by the chemical industry as feed stock (Goldstein 1979). The conversion of wood into ethanol and then to ethylene or butadene would lead to synthetic polymer production. This conversion would release the fossil fuels now being used for this purpose. Converting biomass into plastics for example, would mean the production of another high quality product similar to the chemical celluloses that we are presently producing.

Animal Feed Stocks

The discussion of producing feed stock from biomass leads me to mention one additional minor opportunity--animal feed stock. The use of agri-

cultural products (e.g. corn) for the production of fuels to burn in our cars while thousands of people suffer from starvation raises a serious moral question. While the answer to this question may never be resolved, our forest may become a source for animals and poultry feed. Here again, the Soviet Union is way ahead of us. The production of dried, milled coniferous foliage, termed "muka", is of the order of 100,000 tons per year (Keays 1975). Foresters have been practicing multiuse management of our resource which in some instances included integrating wood and cattle production. The possibility exists to move this integration into our processing facilities to produce feed stock.

RECONSTITUTED WOOD FROM BIOMASS

The way we manage the fourth forest and succeeding forests will be different from our present practices. These new forests will be utilized in every conceivable fashion. We have seen cases today where companies have moved from producing only solid wood products to include processing pulp or paper using smaller material. The reverse direction has also taken place. The majority of companies in the forest industry are either using or selling their waste for energy production.

The concept of totally integrating the processing of woody material for its highest value has been proposed by Kock (1980). This concept includes the maximum utilization of wood from our forest and includes processing roots, topwood and foliage (i.e. biomass).

In addition to being fully utilized, the forests of tomorrow will be managed for maximizing fiber production and not diameter size. This will have a dramatic effect on the economics of growing trees. We will be able to recapture the capital investment required for regeneration in 10 or 15 years.

This hypothesis is derived from the following trends:

1. All the predictions of supply and demand for forest products show a widening gap in the next century. The pressure to manage forests for conservation and recreation rather than fiber production will also increase the demand to increase forest production from a shrinking land base.

2. If interest rates continue to increase faster than stumpage then the penalty for investing in trees for long rotations will become greater.

3. Many manufacturing facilities are coming up with new ways of processing smaller and smaller material, e.g. hardwood bolts for furniture.

4. There is a movement towards the production of structural and industrial panels and boards. These products are of equal or superior quality when compared to solid wood.

Reconstituted Wood Products

The future of using biomass for reconstituted products looks quite promising. The technology to produce these products, e.g. medium density boards, oriented strand boards, wafer boards, etc. already exists. Processing facilities are either in operation or under construction. Market analyses, both domestic and export, predict replacement of plywood and structural lumber with reconstituted materials. The raw material for these products can include pine or mixed hardwoods in an assortment of sizes. The conversion of the sometimes unsalable biomass into a high quality product is probably the best near term opportunity. These products are versatile, durable and uniform. They are presently being utilized in a wide variety of end uses such as residential construction, remodeling or repairs, and furniture. Some utility companies are evaluating reconstituted poles and crossarms. To date these poles are quite durable and show signs of being resistant to insects and woodpeckers.

Recycling of Biomass

The ability to produce reconstituted products from a range of woody materials will allow us to recycle biomass. I predict that in the years to come we will recycle wood in the same fashion that we recycle aluminum cans. Again, Europe is way ahead of us. They constantly recycle the wood from buildings being demolished. The good news is that we are catching up. For example, there is one facility in the United States which is recycling railway ties. Of particular interest is the fact that no preservatives are added in the recycling process since they are already present in the wood chips.

CONCLUSION

Opportunities present themselves in different forms. Some of us create new opportunities while others make use of them as they occur. Unfortunately, the forest industry sometimes lets opportunities pass us by. Some of these latter cases are a result of not wanting to take risks, economic constraints, poor markets and undeveloped technology. Some of these problems are really

opportunities. For example, the problems associated with pulping juvenile wood is an opportunity for forest genetic research. America's forests may be a renewable resource but there are certain limits to its ability to replace itself. We must therefore seek new ways of increasing production and product utilization of this resource.

LITERATURE CITED

Blomqvist, L.
1978. An industrial plant for chipping stump and rootwood for chemical pulping. Proc. of the Symposium on Complete Tree Utilization of Southern Pine pp 294-297.

Curtis, A.B.
1978. Forest residues for energy in the south. 10th Spring Symposium Florida Section, Soc. of Am. For. pp 21-33.

Durso, D.F.
1975. Direct preparation of cellulose derivatives. Proc. of the Symposium on Complete Utilization of Southern Pine pp 305-308.

Frederick, D.J., W.E. Gardner, T.K. Slichter, R.C. Kellison, and M. Williford.
1978. Species selection and silvicultural systems for producing fuels from wood biomass in the southeastern United States. Third Annual Biomass Energy Systems Conference, Colorado 6 p.

Goldstein, I.S.
1979. Energy sources derivable from wood on an industrial scale for individual, communal and manufacturing applications. Special Report for FAO Forestry Department 42 p.

Hemingway, R.W.
1978. Adhesives from southern pine bark. Proc. of the Symposium on Complete Tree Utilization of Southern Pine pp 433-457.

Inman, R.E. and D.J. Salo.
1978. Biomass production of southern tree plantations and its conversion to energy or chemical products. Proc. of the Symposium on Complete Tree Utilization of Southern Pine pp 314-324.

Keays, J.L.
1975. The practical utilization of foliage. Proc. of the Eighth Cellulose Conference.

Koch, P.
1980. Concept for southern pine plantation operation in the year 2020. Jnl. of For. 78:(2)78-82.

Mnzava, E.M.
1981. Village industries versus savanna forest. Unasylva 33:(131)24-29.

Sizego, G.C., J.A. Fox, and D.R. Eaton.
1972. The energy plantation. Intersoc. Energy Convers. Eng. Conf. Seventh Con. Proc. Pap. 729168.

Watts, A.B. and F.G. Manwiller.
1978. Needles and twigs from southern pine. Proc. of the Symposium on Complete Tree Utilization of Southern Pine pp 309-313.

The business meeting summary is unfortunately based on rather poorly taken notes as the tape recorder was inadvertently turned off. The editors wish to apologize for any admissions - it was not intentional.

The meeting was called to order by Dr. Douglas J. Fredricks of the Steering Committee. Dr. V. Clark Baldwin, the Forest Service representative to the Steering Committee, was also present. Mr. Davis Roberts, the industrial representative to the Committee, was unable to attend the meeting. Dr. Fredricks explained to the new Workshop attendees that membership in the Working Group was very informal. An individual's presence at the meeting qualified the individual as a member.

The main topic of discussion was the impact of the increasing size of the meeting attendance over the past few years on the ability of the Workshop to maintain the Working Group's original objective of serving as a forum for the informal discussion of forest biomass research concepts and results. While the meetings have become more structured with formal sessions and published proceedings, the popular consensus seemed to be that the larger attendance was welcomed and provided new viewpoints and suggested directions for future forest biomass research. There were also some well-received comments on limiting the number of sessions so that the time per speaker could be increased for generating more audience discussion.

In other business, Dr. Baldwin mentioned that additional copies of last year's Proceedings were still available. Interested individuals should contact Dr. Baldwin. Clifford Henry from Buckeye Cellulose, and C. W. Comer from the University of Florida volunteered to host next year's meeting. The offer was unanimously accepted. [Editors note - Some weeks after the Workshop we learned that Joseph R. Saucier, USFS, Athens, GA, requested that next year's meeting be held in Athens. Interested persons should contact Mr. Saucier at the Forest Science Laboratory in Athens.]

A questionnaire was distributed during the meeting to all attendees. The purpose of the questionnaire was to provide additional input on the direction and suggest topics for the Steering Committee and future hosts of the Workshop. Twenty three questionnaires were returned and summarized (Table 1). Of the 23 individuals completing the questionnaire, slightly over one-half listed research as their primary job responsibility. Seveny-four percent of the respondents preferred the current meeting format of both formal and informal sessions with a published proceedings. Sixty-one percent specified that the current, informal, organizational structure of the Working Group was preferred over a more formal organization, with or without national affiliation.

Suggested topics for future meetings were placed in rather broadly defined subject areas due to the varying specific interests of the 23 respondents. Each respondent was asked to list, in order of preference, as many topics as desired. The average priority per topic is based on the priority each respondent assigned to the topic(s) he/she listed. The four most listed topics for future meetings were utilization (given by 70 percent of the respondents), harvesting (52 percent, mensuration (39 percent) and sampling (30 percent). Average priorities for the four topics were 1.7, 1.7, 2.3 and 1.9 for utilization, harvesting, mensuration and sampling, respectively.

Other results from the questionnaires showed that 87 percent of the respondents preferred the current annual meeting schedule and that 83 percent preferred holding the meeting in late May, June or early July. Additional comments and suggestions from the respondents are included in Table 1.

Table 1. Summary of Questionnaire Distributed at the Fifth Annual Southern Forest Biomass Working Group Meeting. Based on 23 Respondents.

		Number	Percent
1. Primary Job Responsibility:1/			
a) Research		13	56
b) Inventory		2	9
c) Teaching		2	9
d) Management, Coordinator		4	17
e) Other		2	9
2. Number of Annual Meetings Attended:			
a) One		11	48
b) Two		5	22
c) Three		2	9
d) Four		4	17
e) Five		1	4
3. Preferred Meeting Structure:2/			
a) Informal		5	22
b) Current format		17	74
c) Highly formal		0	0
d) Undecided		1	4
4. Preferred Working Group Organizational Structure:			
a) Current, informal structure		14	61
b) Formal organization with national affiliation		2	9
c) Formal organization w/o national affiliation		1	4
d) Undecided		6	26
5. Suggested Topics for Future Meetings:3/	Number	Percent	Average Priority
a) Utilization	16	70	1.7
b) Harvesting	12	52	1.7
c) Silviculture	5	22	2.6
d) Mensuration	9	39	2.3
e) Economics	6	26	2.3
f) Genetics	2	9	2.0
g) Sampling	7	30	1.9
h) Inventory	2	9	1.5
i) Other	4	17	2.5
6. Importance of Working Group to Job Responsibility (scale of 1 to 10):4/ Average = 7.3 Range = 3 - 10			
7. Preferred Meeting Schedule:		Number	Percent
a) Annual		20	87
b) Bi-annual		2	9
c) Undecided		1	4
8. Preferred Months for Meeting:			
a) May		4	13
b) June		17	57
c) July		4	13
d) Fall		3	9
e) Winter		2	7

9. Comments, Suggestions, etc.
a) Split the meeting into two sessions; applications and research.
b) Continue the trend for more papers on harvesting and utilization.
c) Make use of panel-type format to generate more discussion.
d) Include session(s) on current success in technology transfer for development of biomass utilization.
e) Maintain industrial forester participation.
f) Establish procedure to change steering committee members every 2 to 3 years on a staggered basis.
g) Have fewer papers, allow more time per speaker and also more time for individual research results.
h) Include more on the economics of all aspects of biomass.

1/ If more than one job responsibility was given (e.g. teaching and research), only the first field was recorded.
2/ Informal = Small meeting group, research emphasis only, no published proceedings.
Current = Larger audience and areas of interest, still maintain informal discussions, include both research and applications topics, published proceedings.
Formal = Much larger audience with more diverse interests, possibly concurrent sessions, published proceedings, chance for less discussion due to size and time constraints.
3/ Multi-response question where the respondent was asked to list, in order of preference, topics to be included in future meetings.
4/ 1 = Not Important; 5 = Useful; 10 = Highly Important

ATTENDANCE LIST

NAME	MAILING ADDRESS	REPRESENTING
J. Fred Allen	P.O. Box 819 Macon, GA 31298	Georgia Forestry Comm.
Clark Baldwin	2500 Shreveport Hwy. Pineville, LA 71360	Southern Forest Experiment Sta.
Paul E. Barnett	Div.of Land & For.Res. Norris, TN 37828	Tennesse Valley Authority
John E. Baumgras	Forestry Sciences Lab P.O. Box 152 Morgantown, W.VA 24742	U.S. Forest Services
James T. Bones	1 Mt. Vernon P. Chadds Ford, PA 19317	USDA Forest Service
Dr. Lindsay R. Boring	Dept. of Botany University of Georgia Athens, GA 30602	University of Georgia
Robert T. Brooks, Jr.	Forestry Bldg. Norris, TN 37828	Tennessee Valley Authority
M.S.F. Campbell	School of Forest Resources and Conservation University of Florida Gainsville, FL 32611	University of Florida
James B. Carlaw	P.O. Box 9024 Dallas, TX 75380	International Paper Co.
Alexander Clark	Forestry Science Lab Carlton Street Athens, GA 30602	USDA Forest Service
Dr. C. W. Comer	118 Newins-Ziegler Hall Gainesville, FL 32611	SFRC, University of Florida
Noel D. Cost	200 Weaver Blvd. Asheville, NC 28804	SE Forest Experiment Station
Tiberius Cunia	Suny College of Environmental Science & Forestry Syracuse, NY 13210	Suny College of Environmental Science & Forestry
Richard Daniels	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Bonnie Dumas	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Phil Dunham	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Bruce Fox	Champion International Greenville, SC	Champion International
Douglas J. Fredrick	4405 Dewees Court Raleigh, NC 27612	N.C. State Unviversity

NAME	MAILING ADDRESS	REPRESENTING
Wayne A. Geyer	Forestry Dept. Call Hall K.S.U. Manhattan, KS 66506	Kansas State University
Mark D. Gibson	School of Forestry Box 10138 T.S. Ruston, LA 71272	Louisiana Tech. University
Samuel F. Gingrich	2730 Savannah Hwy. Charleston, SC 29407	USDA Forest Service
Charles A. Gresham	P.O. Box 596 Georgetown, SC	Clemson University
Roger Griffith	121 Hiwassee Street Sheffield, AL 35660	Tennessee Valley Authority
Phil T. Grimm	P.O. Box 3758 Charlottesville, VA 22903	Virginia Div. of Forestry
William Hafley	Raleigh, NC	N.C. State University
William R. Harms	2730 Savannah Hwy. Charleston, SC 29407	USDA Forest Service
Clifford Henry	Perry, FL 32347	Buckeye Cellulose Corp.
Doug Heym	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Lynn B. Hooven	Box 819 Macon, GA 31298-4599	Georgia Forestry Commission
Nancy Hopson	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
John R. Hornick	Box 2417 Washington, DC 20013	USDA Forest Service
Joseph D. Kasile	3725 Seaford Drive Columbus, OH 43220	Ohio State University
Robert C. Kellison	1316 Dixie Trail Raleigh, NC 27607	N.C. State University
Teromo Kotimaki	The Finnish Forest Inst. UNIONINKATU 40 A SF-00171 Helsinki 17 FINLAND	The Finnish Forest Research Institute
F. Thomas Lloyd	2730 Savannah Hwy. Charleston, SC 29407	USDA Forest Service
Richard E. Lohrey	120 Ivy Lane Pineville, LA 71360	Southern Forest Experiment Sta.
Wayne Lininger	Perry, FL 32347	Buckeye Cellulose Corp.
Joe P. McClure	200 Weaver Blvd. Asheville, NC 28804	FIA-SEFES

NAME	MAILING ADDRESS	REPRESENTING
W. V. McConnell	323 Meadowbrook Lane Tallahassee, FL 32304	Consultant
W. Henry McNab	Forestry Sciences Lab. Carlton Street Athens, GA 30602	S.E. Forest Exp. Station
Andrew J. Malmquist	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Gevan R. Marrs	Technology Center WTC2H19 Tacoma, WA 98477	Weyerhaeuser
Neal Menkus	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Charles C. Myers	Southern Illinois U. Carbondale, IL 62901	Dept. of Forestry
E. G. Owens	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Douglas R. Phillips	S.E. Forest Exp. Sta. Clemson University Clemson, SC 29361	U.S. Forest Service
Aga M. Razvi	Westvaco Corporation New York, NY	Westvaco Corporation
D. L. Rockwood	School of Forest Resources and Conservation University of Florida Gainsville, FL 32611	University of Florida
Ken Roeder	Raleigh, NC	N.C. State University
Charlie Rountree	131 Satcher Road Lexington, SC 29072	
Bryce R. Schlaegel	P.O. Box 227 Stoneville, MS 38776	USDA Forest Service
Michael A. Taras	College of For. Rec. Resources Clemson University Clemson, SC 29361	Clemson University
Charles E. Thomas	New Orleans, LA	Southern Forest Experiment Sta.
John Thurmes	P.O. Box WV Summerville, SC 29483	Westvaco Corporation
Judy L. Trimble	P.O. Box X Oak Ridge, TN 37830	Oak Ridge National Lab.
Mike Vasievich	P.O. Box 12254 Research Triangle PK, NC	SE Forest Exp. Station
Thomas A. Walbridge, Jr.	Blacksburg, VA	VA Polytechnic Institute

NAME	MAILING ADDRESS	REPRESENTING
Nancy C. Walczyk	Woodlands Div. P.O. Box 1391 Savannah, GA 31402	Union Camp
Lawrence P. Wilhite	2730 Savannah Hwy. Charleston, SC 29407	USDA Forest Service
James Williams	140 Biscayne Drive Athens, GA 30602	
Ted Yarosh	P.O. Box 2417 - TM Washington, DC 20013	Forest Service USDA

Sample Citations

Entire Book

Daniels, R. F.; Dunham, P. H., eds.
Proceedings of the 1983 southern forest biomass workshop. Fifth annual meeting of the Southern Forest Biomass Working Group; 1983 June 15-17; Charleston, SC. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 121 p.

Single Article

Kellison, R. C.
The total biomass concept: its impact on traditional silviculture. In: Daniels, R. F.; Dunham, P. H., eds. Proceedings of the 1983 southern forest biomass workshop. Fifth annual meeting of the Southern Forest Biomass Working Group; 1983 June 15-17; Charleston, SC. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984: 3-9.

Daniels, R. F.; Dunham, P. H., eds.
Proceedings of the 1983 southern forest biomass workshop. Fifth annual meeting of the Southern Forest Biomass Working Group; 1983 June 15-17; Charleston, SC. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1984. 121 p.

A collection of 25 papers describing research on the measurement and utilization of forest biomass and telling how findings are being used.

KEYWORDS: Mensuration, estimation, utilization, research planning, forest inventory.

☆U S GOVERNMENT PRINTING OFFICE [illegible] REGION NO 4